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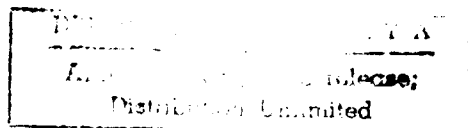
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# Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 14th US/Japan  
Experts Meeting

27 February-1 March 1990  
Yokohama, Japan

Thomas R. Patin, Editor



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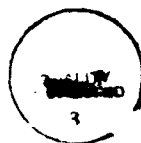
## PREFACE

The 14th US/Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances was held 27 February-1 March 1990 in Yokohama, Japan. The meeting is held annually through an agreement with the US Army Corps of Engineers and the Japanese Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

Mr. Jimmy F. Bates, Chief of the Policy and Planning Division, Directorate of Civil Works, US Army Corps of Engineers, was the US Chairman.

Mr. Takashi Hashikawa, Director of the Environment Division, Ports and Harbours Bureau, Ministry of Transport, was the Japanese Chairman.

Coordinator of the organizational activities and editor of this report was Mr. Thomas R. Patin, Program Manager, Dredging Operations Technical Support (DOTS) Program, US Army Engineer Waterways Experiment Station (WES). Miss Phyllis Davis, contractor editor for the WES Information Technology Laboratory (ITL), and Mrs. Jessica Ruff, ITL editor, were responsible for editing and coordinating the text for publication. Dr. Robert M. Engler was Program Manager of the Environmental Effects of Dredging Programs, of which the DOTS Program is a part.



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## ATTENDEES

### 14th US/JAPAN EXPERTS MEETING ON MANAGEMENT OF BOTTOM SEDIMENTS CONTAINING TOXIC SUBSTANCES

#### US Delegation

Jimmy F. Bates Co-Chairman	Chief, Policy and Planning Division, Directorate of Civil Works, US Army Corps of Engineers
Mark J. Otis	Supervisory Civil Engineer, US Army Engineer Division, New England
Michael R. Palermo	Research Civil Engineer, US Army Engineer Waterways Experiment Station
Jacob F. Redlinger	Civil Engineer, US Engineer Division, North Pacific
John F. Tavoraro	Chief, Water Quality Compliance Branch, US Army Engineer District, New York
Catherine C. Krueger	Chief, Hazardous Waste Program Section, US Environmental Protection Agency, Region 10
Spencer A. Peterson	Regional Scientist, US Environmental Protection Agency, Region 10

#### Japanese Delegation

Takashi Hashikawa Co-Chairman	Director, Environment Division, Ports and Harbours Bureau, Ministry of Transport
Mitsugu Kawada	Environment Division, Ports and Harbours Bureau, Ministry of Transport
Munekazu Hirose	Kumamoto Port Construction Office, Ministry of Transport
Masaharu Nakamura	Japan Sediments Management Association
Tatsunori Kosaka	Kansai International Airport Company, Ltd.
Zen-ya Yoshino	Tokyo Science University
Jun-ichi Hamasuna	Chairman of Technical Committee, Japan Sediments Management Association

Takeo Maekawa	Japan Dredging and Reclamation Engineering Association
Kiyoshi Nikaido	Japan Sediments Management Association
Yasuyuki Nakayama	Nagoya Port Construction Office, Ministry of Transport
Hazime Matsui	Second District Port Construction Bureau, Ministry of Transport
Yasushi Hosokawa	Port and Harbour Research Institute, Ministry of Transport
Masashi Kamon	Department of Civil Engineering, Kyoto University
Nobuaki Wada	Japan Sediments Management Association
Takeshi Chiba	Japan Dredging and Reclamation Engineering Association
Tsuneyoshi Tanaka	Port and Harbour Bureau, Yokohama City
Kiyoyasu Mikanagi	General Director, Ports and Harbours Bureau, Ministry of Transport
Hisato Yamada	Director, Second District Port Construction Bureau
Koh-Ichirou Miyahara	Vice-Mayor, Yokohama City
Wataru Kitamura	Director, Port and Harbour Bureau, Yokohama City

## AGENDA

### 14th US/JAPAN EXPERTS MEETING ON MANAGEMENT OF BOTTOM SEDIMENTS CONTAINING TOXIC SUBSTANCES

Yokohama, Japan  
27 February - 1 March 1990

#### Co-Chairmen

Mr. Takashi Hashikawa  
Director, Environment Division  
Ports and Harbours Bureau, Ministry of Transport, Japan

Mr. Jimmy F. Bates  
Chief, Policy and Planning Division  
Directorate of Civil Works, US Army Corps of Engineers

#### Tuesday, February 27, 1990

0900-0930	Opening Ceremony
0930-1000	Mr. Mitsugu Kawada, "Summary of Marine Environment Work"
1000-1030	Mr. Jimmy F. Bates, "Overview of Significant Issues and Trends in the US Dredging Program"
1030-1045	Coffee
1045-1115	Mr. Munekazu Hirose, "Mercury-Contaminated Sediment Disposal Work in Minamata Bay"
1115-1145	Mr. Masaharu Nakamura, "Restoration of Lake Shibayama"
1145-1300	Lunch
1300-1330	Mr. Tatsunori Kosaka, "Construction of Kansai International Airport"
1330-1400	Mr. Mark J. Otis, "A Pilot Study of Dredging and Disposal Alternatives for the New Bedford Harbor, Massachusetts, Superfund Site"
1400-1430	Mr. Zen-ya Yoshino, "Development of the High Rate Dewatering System of Bottom Sediments and Water Blooms"
1430-1500	Mr. Jun-ichi Hamasuna, "Example of Latest Techniques for Bottom Sludge Dredging"
1500-1515	Coffee

1515-1545 Mr. Michael R. Palermo, "An Update of Dredged Material Capping Experiences in the United States"

1545-1615 Mr. Takeo Maekawa, "Treatment of Dredged Sludge by Mechanical Dehydration"

1615-1645 Mr. Kiyoshi Nikaido, "Investigation on Resuspension of River Sediments Using the Annular Flume During Rainfall"

1645-1715 Mr. Jacob F. Redlinger, "Hopper Dredges Applied to the Alaska Oil Spill, March 1989"

1715-1745 Mr. Yasuyuki Nakayama, "Oil Cleanup with a Large Skimming Vessel in Wakasa Bay, February 1990"

1800- Ministry of Transport Reception (Yokohama International Conference Center Lounge)

Wednesday, February 28, 1990

0900-0930 Mr. Hazime Matsui, "Influence of Anoxic Water in Tokyo Bay and Its Management Planning"

0930-1000 Mr. Yasushi Hosokawa, "Proposal of the SEA-BLUE Program-- Application of Natural Energies and Biological Activities to Water Quality Improvement Along Coast"

1000-1030 Coffee

1030-1100 Mr. John F. Tavoraro, "The Problem of Dioxin Contamination in Sediments of the Port of New York and New Jersey"

1100-1130 Mr. Masashi Kamon, "New Soil Stabilizer from the Combination of Industrial Waste"

1130-1200 Ms. Catherine C. Krueger, "Developing Sediment Quality Standards: Comprehensive Sediment Management in Puget Sound"

1200-1330 Lunch

1330-1700 Excursion by Yokohama City (Yokohama Port, etc.)

1830- US Reception

Thursday, March 1, 1990

0900-0930 Mr. Nobuaki Wada, "Solidification Technique for Dredged Bottom Sediments"

0930-1000 Mr. Takeshi Chiba, "Development of a Vacuum Consolidation Method Employing Horizontal Drains"

1000-1015	Coffee
1015-1045	Mr. Spencer A. Peterson, "Toxicological Assessment of Hazardous Waste Sites"
1045-1115	Mr. Tsuneyoshi Tanaka, "Follow-up Investigation of Marine Life Around the Artificial Sandy Beach of Yokohama Marine Park and Problems Concerning Maintenance and Management of the Beach"
1115-1145	Closing Remarks
1145-1800	Free
1800-	Yokohama City Reception (Hotel Yokohama)
<u>Friday, March 2, 1990</u>	
0830-1700	Excursion by Ministry of Transport (Yokohama--Port and Harbour Research Institute--Kamakura--Yokohama)

## JOINT COMMUNIQUE

### 14th MEETING OF US/JAPAN EXPERTS ON MANAGEMENT OF BOTTOM SEDIMENTS CONTAINING TOXIC SUBSTANCES

FEBRUARY 27-MARCH 1, 1990

YOKOHAMA, JAPAN

The 14th meeting of Experts on Bottom Sediments Containing Toxic Substances was held from February 27 to March 1, 1990, in Yokohama, Japan, pursuant to the Agreement between the Government of the United States of America and the Government of Japan on Cooperation in the Field of Environmental Protection signed in Washington, DC, on August 5, 1975, and renewed in 1980 and 1985. Mr. Jimmy F. Bates, Chief, Policy and Planning Division, Directorate of Civil Works, US Army Corps of Engineers, and Mr. Takashi Hashikawa, Director, Environment Division, Ports and Harbours Bureau, Ministry of Transport, Japan, co-chaired the meeting.

The purpose of the meeting was to continue to implement Article I of the 1975 US-Japan Agreement by conducting mutually beneficial meetings of experts to explore, discuss, and exchange information on technical and operational areas, aspects of the management of bottom sediments, and related research development activities, policies, practices, legislation, and regulations.

Scientific and engineering experts from both countries presented technical papers on a variety of subjects, including operational and pilot demonstration projects and research programs to evaluate and protect the environment. More specifically, the experts discussed evaluating and predicting the behavior of nutrients, organics, and other contaminants in both in-place and dredged sediments; pilot projects and demonstrations on innovative dredging and sediment treatment technologies; follow-on environmental programs to evaluate the success of sediment removal and treatment operations for environmental protection; and identification and evaluation of the many alternatives for dredging and disposal of contaminated sediments from lakes, rivers, waterways, estuaries, and marine waters associated with these sediments. New, innovative, and cost-effective technologies including the uses of marine energy and biology were stressed, and management practices with the most promising long-term utility were emphasized.

This 14th meeting involved a successful and productive exchange of information relating to the dredging technology and sediment management programs of both countries. To better utilize the knowledge gained and lessons learned from these exchanges, the Co-Chairmen discussed the possibility of publishing detailed proceedings which would contain each of the presentations made during the 14th Meeting and of exchanging a title list of papers on the management of bottom sediments published every year in both countries, and holding the next (15th) meeting in the United States in November 1991, at a site and time to be



determined later. Such a meeting would be held in accordance with an agenda to be mutually agreed to in the future.

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Jimmy F. Bates  
Chief  
Policy and Planning Division  
Directorate of Civil Works  
US Army Corps of Engineers  
March 1, 1990

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Takashi Hashikawa  
Director  
Environment Division  
Ports and Harbours Bureau  
Ministry of Transport  
March 1, 1990

OVERVIEW OF SIGNIFICANT ISSUES AND TRENDS  
IN THE US DREDGING PROGRAM

Jimmy F. Bates

Chief, Policy and Planning Division  
Directorate of Civil Works  
US Army Corps of Engineers  
Washington, DC

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INTRODUCTION

The purpose of these introductory remarks is to provide the Japanese Delegation with a brief overview of significant accomplishments that have occurred in the US Program since the last meeting some two years ago. These remarks will also represent what is seen as some of the major emerging issues and US Research directions and information needs in the field of contaminated bottom sediments management. The objectives of this overview are:

- a. To serve as a general introduction to the papers to be presented by the US Delegation.
- b. To provide the basis for information exchange, including any requested follow-on information that the Japanese Delegation might desire, on topics of interest which cannot be presented in detail during our short visit here in Japan.
- c. To act as a mechanism to initiate information dialogue with the Japanese Delegation on topics of particular interest to the US Delegation, both during this and follow-on meetings.

SUMMARY OF RECENT ACCOMPLISHMENTS AND EVENTS

Reorganization

In prior meetings, the US co-chairman has been a military officer who also served as the Director of the Corps Water Resources Support Center and the Corps Dredging Division, which had the US responsibility for these Memorandum of Understanding (MOU) meetings. There has since been a major reorganization within the Corps, with the broad responsibilities of the Dredging Division reassigned as a Corps Headquarters management function. As part of this reorganization, the responsibility for the environmental management activities associated with dredging and dredged material disposal was assigned to me as Chief of the Corps' Policy and Planning Division. As such, my boss, the Assistant Secretary of the Army (Civil Works), felt that it would be more appropriate for me to assume the duties as US Co-chairman for these MOU meetings.

The US representation in the future MOU meetings will remain in somewhat of a dynamic state dictated in part by what the US Congress eventually defines as the appropriate roles and responsibilities at the Federal level in bottom sediment cleanup projects within the US waterways. It is clear, however, that

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both the Corps and the Environmental Protection Agency (EPA) will continue to play a major role in this area and in future MOU meetings.

### Port Deepening

Since the last meeting the United States has made significant progress in its national construction dredging initiative to deepen our major coastal deep-draft ports and harbors under cost-sharing requirements of that authorizing legislation. Most affected ports have opted for a phased construction process wherein channels are to be deepened to 50 ft with a decision on eventual construction to 55-ft depths contingent on future economic conditions and trends. To date, this effort has involved removal of over 250 million cu yd of new work dredged sediments. Physical and not chemical contamination impacts relating to these extremely large volumes of sediments have been the overriding environmental concern. It is good to be able to report that many of the innovative beneficial use concepts employed during this construction and reported at prior meetings have been quite successful, and some excellent operational experience and data are being developed on these concepts. Two of the more innovative and promising concepts for future program application are submerged berms and wetlands rehabilitation projects.

### Submerged Mounds

The concept of submerged mounds is to take advantage of the large volumes of clean sediments derived from construction dredging. We use pinpoint placement in nearshore ocean waters parallel to the beach for the multipurpose benefits of replenishing the adjacent beach in a cost-effective manner, storm-wave and beach erosion attenuation by the berm feature itself, and enhanced biological habitat through feature construction in the relatively nonproductive nearshore coastal zone. Three demonstration projects presently under study have applied this concept, and the preliminary data indicate that the three anticipated benefits can be satisfactorily realized through proper design and orientation of those dredged sediment features.

### Wetlands Rehabilitation

To date, the United States has constructed or rehabilitated over 50,000 acres of coastal wetlands with about 30,000 acres of this total derived from rehabilitation of Louisiana coastal wetlands with dredged sediments from port construction activities. Operational experience will continue to be developed with a variety of dredging plants using thin-lift sediment placement techniques. Such experience will always be a high-priority need within the United States due to the critical environmental value of and continuing losses of wetlands habitat. Also, primary regulatory emphasis will be on rehabilitation as opposed to construction of new wetlands due to concerns over the loss of other coastal aquatic and upland habitat.

Next, the status of other US initiatives that have been reported during previous meetings will be summarized.

### Multiple Uses of Upland Disposal Sites

The concept is to use confined dredged material disposal sites for other beneficial purposes such as maricultures while simultaneously using these

sites for dredged material disposal. Our primary interest is to define economic incentives to landowners in our efforts to retain existing upland sites as well as to locate suitable new upland disposal sites. This problem is particularly acute for many of our coastal navigation projects where land is extremely scarce and in great demand from many competing interests. A pilot demonstration project was just completed in Brownsville, Texas, involving mariculture of commercial shrimp species. The preliminary data and market analyses indicate that such multiple-use concepts do have considerable potential application in many coastal areas of the United States, both from an environmental and economic perspective.

#### Ocean Disposal Testing Guidance Revision

The Corps and EPA have just released for public review proposed revisions to our national environmental testing guidance for dredged sediments proposed for ocean disposal. This document includes revised and updated guidance on acceptance bioassay test species, procedural requirements for undertaking and interpreting bioassays, quality control procedures, and accepted analytical procedures for chemical contaminant analyses.

#### Disposal Management Strategy Technical Guidance

It is our hope to jointly publish later on this year with EPA a technical guidance document that lays out a framework for evaluating all alternatives (upland, open water, etc.) for disposal of dredged material, from the cleanest to the dirtiest. The document will include accepted evaluation procedures for testing the effectiveness of engineering controls or management restrictions such as in-water capping for highly contaminated dredged sediments. Our intent here is to consolidate the international scientific knowledge, including Japanese experiences obtained through these MOU meetings, into a comprehensive disposal management strategy and to periodically make revisions to keep current with the international scientific literature in this area. Dr. Mike Palermo of the Waterways Experiment Station (WES) will present an overview update of recent US experience with capping, which is to be incorporated into this strategy document.

#### Oil Spill Cleanup

The events surrounding the catastrophic oil spill in Valdez, Alaska, last summer have probably been followed in some detail by everyone present. What may not be known is that several Corps hopper dredges were called into service to assist in that cleanup. Mr. Jake Redlinger of the North Pacific Division in Portland, Oregon, will describe our experiences in that effort. Based on our involvement, there is renewed US interest in appropriately retrofitting several of our Federally owned hopper dredges to better assist in future oil spill cleanup efforts. Furthermore, the United States is fully aware of the international technology and capabilities in this area and is proceeding cautiously in defining the most appropriate future role for Corps dredges in this type of activity.

## Shellfish Habitat Creation

A demonstration project that was reported on during the 13th meeting in Baltimore involved creation of a new oyster habitat within Chesapeake Bay using dredged sediment. The disposal site was located in a previously highly productive oyster reef which was decimated because of siltation or other phenomena, either man-induced or natural. The operation consisted of using dredged sediments to raise the bottom elevation above the bottom turbidity layer and then to apply a cap of oyster shell for optimum recolonization. The operation was a complete success operationally, economically, and environmentally. Our efforts now consist of follow-on productivity monitoring of the new reef as well as in developing a disposal management plan that will allow use of the area for up to 50 years for disposal and simultaneously provide for phased and systematic construction of additional reef habitat in a manner that does not impact previous habitat construction efforts.

## EMERGING ISSUES/NEEDS IN THE US PROGRAM

Three specific areas that will to a great extent influence future US participation and technical information exchange needs in these MOU meetings will be discussed next. The first, as in past meetings, is the general area of navigation maintenance and our continuing high-priority efforts to ensure that extensive dredging and dredged material disposal activities are undertaken in both a cost-effective and environmentally responsible manner. On the environmental side, one of the major continuing priorities is the development of predictive tests to measure chronic or sublethal effects of dredged sediments with particular focus on man-made organic compounds. Mr. John Tavolaro of the Corps New York District will discuss ongoing US efforts with one of the most difficult US problem areas at present, i.e., the issue of Dioxin-contaminated sediments. Of course, any ongoing or planned Japanese research in the general area of chronic, sublethal effects will interest us.

On the dredging side, a major new research program, the Dredging Research Program or DRP, which is oriented in large part to improving both our dredging plant and dredging operation management efficiencies, has just been started. Our Delegation hopes to maintain close coordination with the Japanese Delegation throughout the duration of this program. Areas of particular interest to US researchers in DRP are innovation in automated dredging plant and subaqueous rock excavation techniques.

The second and rapidly emerging issue in the United States is the cleanup of highly contaminated bottom sediments. The US Congress is expressing considerable interest in establishing and funding a national program in this area. As mentioned earlier, the relative roles and responsibilities of the Corps and EPA in this program, while uncertain at present, are both expected to be major ones. Ms. Catherine Krueger of EPA Region 10 in Seattle, Washington, and Mr. Mark Otis of the Corps New England Division will give papers on two of the major ongoing US cleanup projects to date involving highly contaminated bottom sediments. The innovative Japanese technology and operational experience in this area are well known to us through previous MOU meetings; as US co-chairman, it will be my responsibility to ensure that this information continues to be made available to US scientists and engineers. As the development of operational cleanup projects proceeds cautiously in the United States, one area of particular interest and need from the US side in

this area will be any long-term environmental monitoring data that might have been generated by Japanese scientists and engineers as part of follow-on studies of completed operational cleanup projects in Japan. Other related areas of particular interest to the US Delegation in this area are Japanese experiences in research on sediment stabilization procedures and technologies and in volatilization of contaminants at the sediment/air interface in confined disposal sites.

The final area of increased US emphasis and information needs, again where Japan has developed some very valuable and important operational experience, is in the area of lake restoration. By the year 2000, many of the major man-made reservoirs in the United States will have surpassed their 50-year project design life, and some will require major engineering rehabilitation (possibly involving dredging) to restore intended project purposes such as flood storage, drinking water supply, and navigation. The US Congress has recently demonstrated new interest in this area, and Mr. Spencer Peterson of EPA will present a paper on ongoing US research and development activities, as well as his views on priority US information needs in this area.

# MERCURY-CONTAMINATED SEDIMENT DISPOSAL WORK IN MINAMATA BAY

M. Hirose

Kumamoto Port Construction Office, Ministry of Transport  
1259-7, Yahata-machi, Kumamoto C., 861-41, Japan

A. Yamaguchi

Environmental Pollution Department, Kumamoto  
Prefectural Government  
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**AD-P006 452**



## ABSTRACT

To root out Minamata disease, which is representative of pollution-caused diseases, a large-scale sediment disposal work was conducted with special care to prevent the secondary pollution due to the work.

The basic approach for disposal work consisted mainly of two kinds of ideas. One was to install boundary nets to prevent the mixing of contaminated fish in the Minamata Bay area and noncontaminated fish outside the Bay. The other was to dredge mercury-contaminated sediment without disturbance and to confine it in the reclamation area, enclosed by highly watertight revetment.

This work was commenced in 1977 and is going to be successfully completed in March of this year with the disposal of roughly 1.5 million cubic meters of sediment over a 2 million-square meter area.

## INTRODUCTION

This paper outlines the mercury-contaminated sediment disposal work conducted in Minamata Bay as an example of public pollution control work. In Minamata City, located at the southernmost end of Kumamoto Prefecture in southwestern Japan (Figure 1), sewage from a chemical factory caused Minamata disease. Methyl mercury contained in the sewage accumulated in fish and shellfish in Minamata Bay, causing toxic central-nervous system disease in those who ate such fishery products in large quantities over a long period of time. So far, over 2,000 people have been recognized as Minamata disease patients, of whom roughly 900 have died. The solution to this problem thus became a most critical task in Japan's environmental administration.

To solve this problem at its roots, it was planned that polluted fish in the Bay would be made inaccessible to consumers and that mercury sludge deposited over an area of about 2,090,000 m<sup>2</sup> in the Bay would be disposed of to

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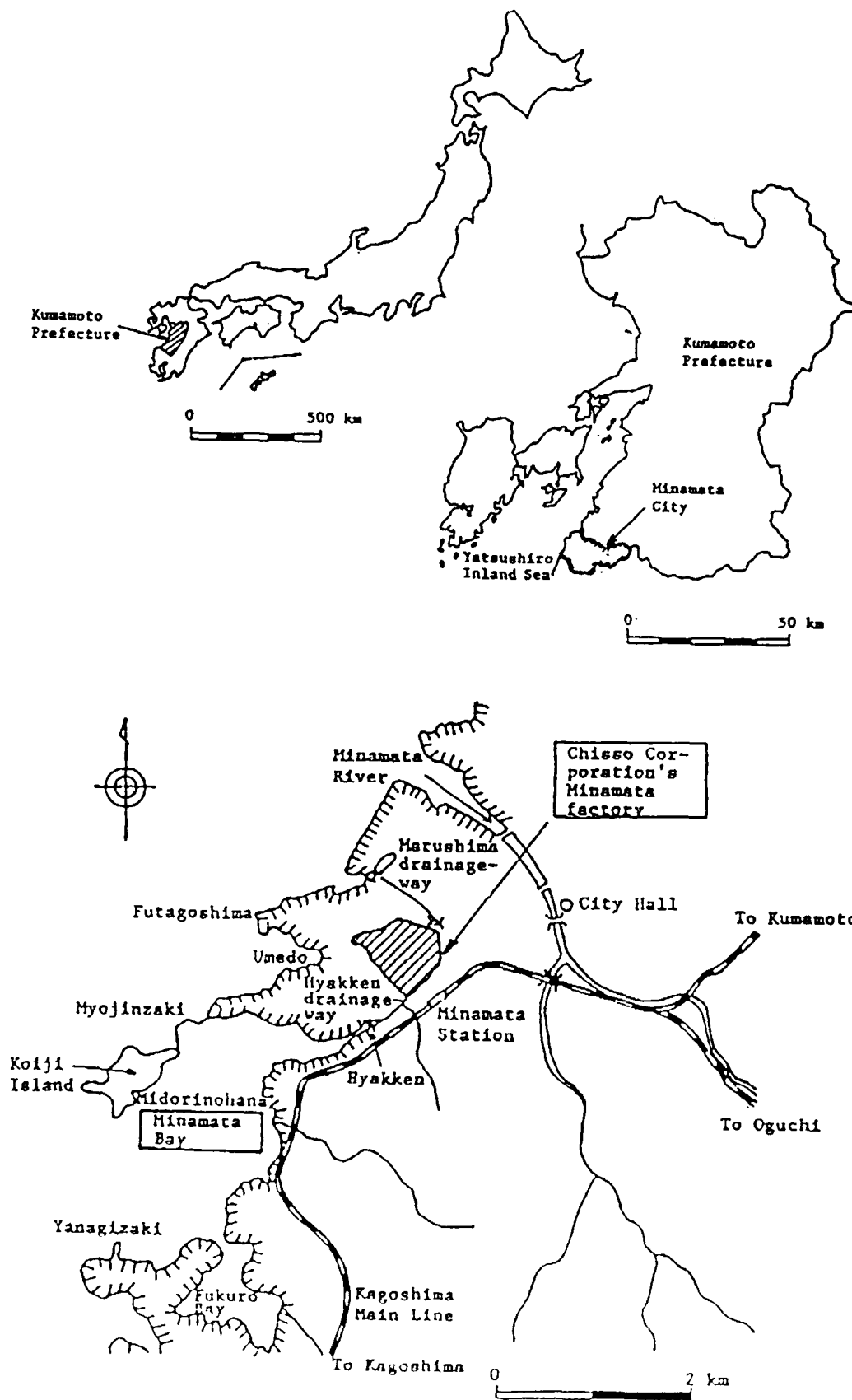


Figure 1. Location of Minamata City

restore the Bay's clean environment. The basic approach to sediment disposal was to construct a highly watertight revetment to reclaim the inner area of the Bay, to dredge sediment from the remaining contaminated area, and then to confine it in the reclamation area. When a plan in line with this approach was finalized by the Kumamoto Prefectural Government, the disposal work was commenced in 1977. Prior to sediment disposal, boundary nets were installed to enclose the work area, with an acoustic fishway controller installed at the navigation opening to prevent the mixing of contaminated and noncontaminated fish. During the whole period of work, special care was taken to complete the work as quickly as possible and to prevent a new public nuisance due to work implementation.

Work was implemented, on commission by the Kumamoto Prefectural Government, the Ministry of Transport, which had extensive experience in sludge-related work, particularly in Japanese ports and harbours. As a result of the active effort by a number of people taking part in the work, sediment dredging was finished in December 1987. Then, on February 26, 1988, the Kumamoto Prefecture Minamata Bay Public Pollution Control Work Supervisory Committee confirmed, on the basis of sediment sampling and analysis result, that all sediment with mercury concentrations exceeding the criterion had been removed. This result showed the successful completion of mercury-contaminated sediment disposal work in Minamata Bay.

## PLANNING

### Mercury Sediment and Minamata Disease

Minamata Bay is a small bay in Yatsushiro Inland Sea. This Bay, whose mouth is protected by Koijishima Island, forms a naturally excellent port, which has been developed as a key access to the Minamata-Ashikita industrial area, home to many chemical factories, and as the base for sightseeing boats linking nearby tourist islands called Amakusa and the mainland called Kyusyu.

However, over a long period of time, from 1932 to 1968, mercury-containing sewage had been drained from Chisso Corporation's Minamata factory into the Bay, causing the development around 1953 of what is now called Minamata disease. The disease was first officially recognized as a pollution-related disease in September 1968. This toxic central-nervous system disease was caused by long-term ingestion of the Bay's fishery products with high mercury concentrations.

### Planning for Mercury Sediment Disposal

#### Developments Toward Implementation

In March 1974, the Director-General of the Environmental Agency, the Minister for Transport, and the Governor of Kumamoto Prefecture reached a basic agreement on the implementation of Minamata Bay public pollution control work. This agreement specified that the Kumamoto Prefectural Government, the manager of the Port, be responsible for the work, while the Ministry of Transport be commissioned to implement the major part of the work, primarily because of its scale and rich experience in this kind of work. Subsequently, governmental agencies and experts were concerned with detailed studies, which the Kumamoto Prefectural Government used in June 1975 to develop the Minamata

Bay Sludge Deposit Disposal Plan and the Basic Plan for Supervision of Minamata Bay Sludge Deposit Disposal. In accordance with the Disposal Plan, the Kumamoto Prefectural Government commenced in October 1977, prior to the major work, installing boundary nets to block fish movement into and out of the work area.

In December 1977, however, some local residents, who were concerned as to the occurrence of a secondary public nuisance due to the work, applied to the Kumamoto District Court for a provisional injunction against sludge dredging in Minamata Bay. In response, the national government and the Prefecture temporarily suspended work to avoid local confusion and strove in court to achieve the residents' understanding of work safety. Consequently, the application was dismissed in April 1980, and the work was resumed in June.

#### Basic Plan for Mercury Sediment Disposal

Disposal of sediment with 25 ppm or higher total mercury concentration was planned--a criterion calculated on the basis of the Provisional Standards for Removal of Mercury-Containing Sludge, established in August 1973 by the Environment Agency, and finalized through the deliberation of the Kumamoto Prefectural Antipollution Measure Council. Accordingly, it was necessary to dispose of roughly 1,510,000 m<sup>3</sup> of sludge from an area of about 2,090,000 m<sup>2</sup> in Minamata Bay. Contamination was serious in terms of both mercury concentration and sediment thickness in the Bay's inner area, into which sewage flowed from Chisso's Minamata factory. Contamination gradually lessened toward the outside of the Bay (Figure 2).

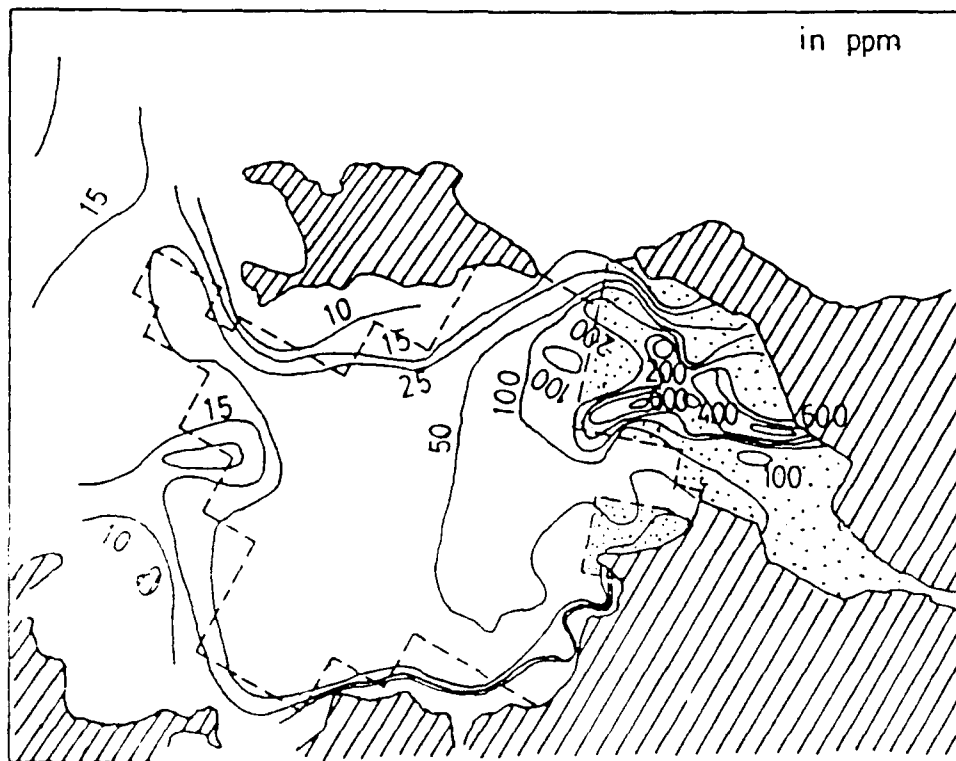


Figure 2. Mercury concentration distribution (before planning)

It was planned that the most severely polluted inner area, 580,000 m<sup>2</sup> in size, would be enclosed with a highly watertight revetment, reclaimed with sludge dredged from the remaining work area, and ultimately covered with good-quality mountain soil.

Existing port facilities in Minamata Bay, all in the newly planned reclamation area, were to be totally phased out of service as the work progressed. To replace them, Zone 1 (for constructing the so-called Midori wharf in advance through preceding work) was planned outside the main reclamation area called Zone 2, shown in Figure 3. In Zone 2, all stages of work, from revetment construction to dredging and reclamation, were to be conducted but on a small scale; therefore, this zone was also regarded as a pilot zone for checking the safety of the work method to be adopted.

To prevent polluted fish from mixing with nonpolluted fish, double fish netting was to be installed to enclose the work area during work and for an appropriate length of time thereafter if necessary, except at the navigation route where an acoustic fishway controller was used to keep the fish off. After the completion of sludge disposal, fish in the work area and boundary nets will be removed.

Figure 3 shows the sediment disposal plan along with the water quality monitoring points that are mentioned later.

#### Prevention of New Public Nuisance

The measures taken to prevent a new public nuisance due to work implementation are as follows:

- a. First, to stabilize water in the dredging area and in front of the reclamation area, a cofferdam was temporarily constructed between Koijishima Island and Myojinzaki's end prior to work. This cofferdam stagnated the intrabay current, thus accelerating the suspended-sludge settlement and preventing this sludge from spreading out of the Bay.
- b. Second, until reclamation sludge was completely confined with mountain soil, the reclamation area was kept under water to prevent direct sludge exposure to sunlight and air. As it was pointed out, this exposure might methylate inorganic mercury in sludge.
- c. Third, to anticipate and avoid a secondary public nuisance, the Kumamoto Prefectural Government established a system for monitoring the influence of mercury-sludge dredging on water quality, fishery products, and plankton.

Besides, prompt feedback of monitoring results of water quality to work was ensured. It was also decided that these monitoring results should be promptly announced officially to residents and referred to the supervisory committee, organized by experts, resident representatives, etc. If such results were found to deviate from the supervisory standards, work should be suspended, or other relevant measures taken.

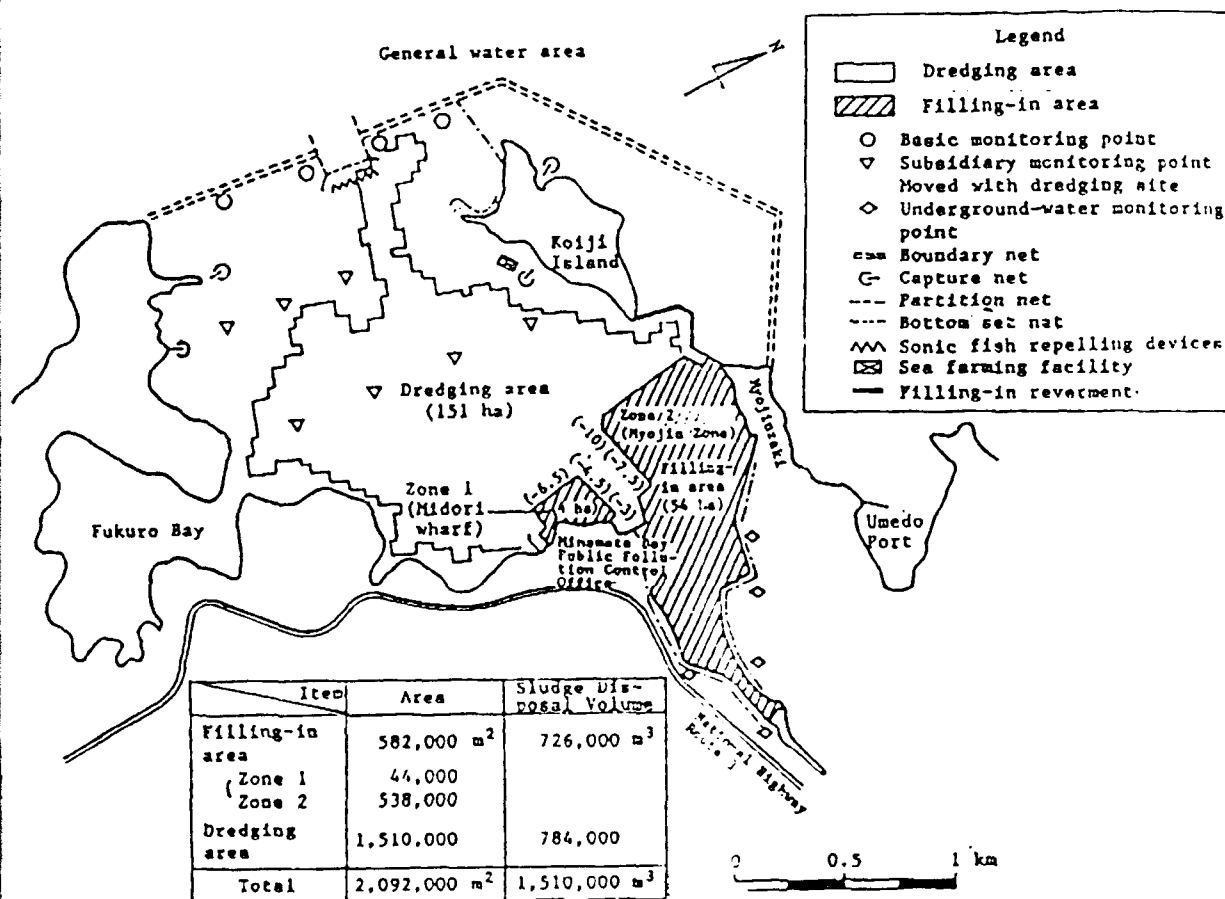


Figure 3. Sludge disposal plan and water quality monitoring points

## REVETMENT

### Structural Type Selection

#### Design Requirements

Reclamation revetment for mercury sediment confinement had not only to withstand earth pressure of reclaimed sludge, wave force, and earthquake motion, but also to be sufficiently watertight to prevent mercury exudation. Since earthquakes are particularly frequent in Japan, maintenance of watertightness even during earthquakes was of vital importance. Another requirement was to securely and promptly secure the revetment to overcome the problem caused by existence of thick silt deposits on the seabed. In consideration of these requirements, the steel sheet pile cellular cofferdam type revetment was adopted.

## Steel Sheet Pile Cellular Cofferdam Type Revetment

A steel sheet pile cellular structure is usually made of steel sheet piles assembled into a cylindrical shape cell, which is filled with sand or gravel. Since the earth pressure of the fill in the cell is supported by cell tensile force, such a structure of unified cell and fill is self-sustained and excellent in water shielding.

The simplest form of this type of structure is detached circular cells, which are often used as dolphins and detached piers. This structure can also be used to construct continuous walls in various ways, of which the continuous circular cell technique was chosen for the present work. The detached cell type, already in wide use in Japan, is high in work safety because each cell was self-sustained in design, but the continuous wall type was more stable because of the restriction of each cell's movement. In the continuous type, circular cells are constructed separately and then linked together.

In the present work, cells roughly 30 m in diameter were used with sand filling, as a result of design consideration. Figure 4 shows a view of the steel sheet pile cellular structure and its installation, and an example of its design section at the mooring part with the soil improvement.

### Construction Revetment

#### Soil Improvement

The upper layer of seabed in Minamata Bay (about 10 to 20 m thick) consists of soft silt deposits with a soil strength of almost zero N-value. Thus, soil improvement was required to maintain the structural safety of the revetment. Selection of soil improvement methods depends on how each part of the reclamation revetment will be used in the future after the disposal work. Considering also other factors involved in this project, basically, the sand compaction pile method was adopted for the mooring portion and the sand drain method for the remainder.

Prior to soil improvement work, the sediment was covered with sand, using an exclusive sand-scattering working ship with a special function, to prevent work disturbance of bottom sediment, insofar as possible.

#### Steel Sheet Pile Cellular Cofferdam

To construct the cellular cofferdam with high precision in a short time, the prefabrication method of construction was used in this work. In this method, sheet piles were assembled in advance into cylindrical form and driven into a fixed place of the reclamation revetment to be planned, simultaneously.

The procedures for installing a cell were as follows:

- a. Sheet piles assembly into a circular-cell-shaped guide frame at the assembly base in water of Minamata Bay.
- b. Guide frame erection with assembled sheet piles in place to be driven.

# Steel Sheet Pile Cellular Structure

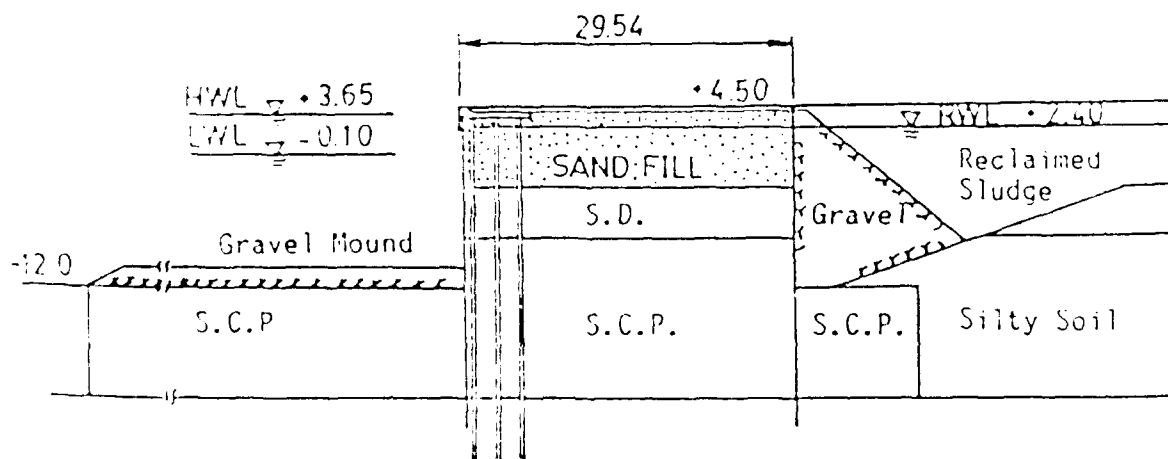
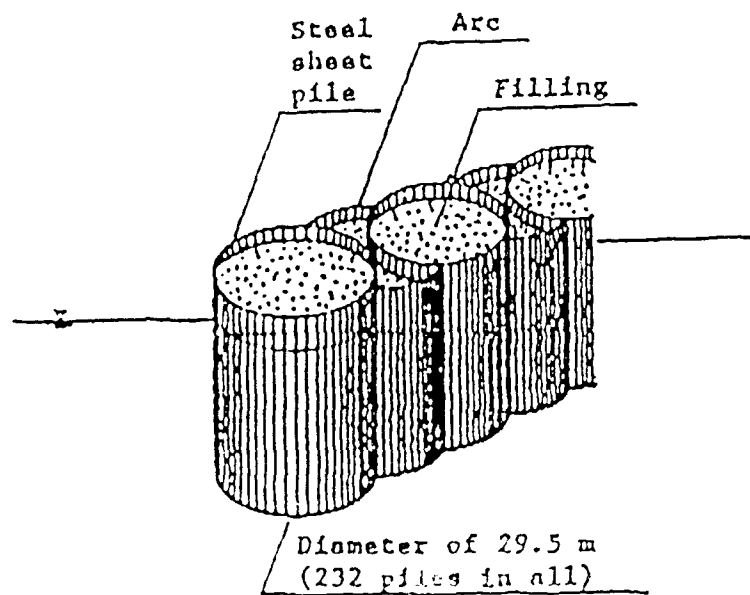


Figure 4. Installation and the standard design section of steel sheet pile cellular structure

- c. Simultaneous driving of all 232 sheet piles with 48 vibrohammers for each cell.
- d. Removal of guide frame and filling of a cell with sand.

After all cells were installed, they were linked to each other with the sheet piles assembled into an arc-shaped plate to make a continuous wall.

## MERCURY SEDIMENT DREDGING

### Basic Concept

#### Dredging Planning

The important points kept in mind in sediment dredging were minimization of the work period to eliminate resident anxiety as early as possible, and the control of muddiness to prevent a new public nuisance. On the other hand, it should be noted that:

- a. Most of the mercury contained in the sediment in Minamata Bay is inorganic, which does not easily desorb from the soil particles into the water.
- b. Methylation of inorganic mercury in dredging poses no problem if aerobic conditions can be avoided.

Special care was also paid to minimize extra dredging so as to permit the accommodation of all dredged sediment in the reclamation area as planned and to achieve the completion as early as possible. Mercury was contained basically only in the upper thin layer of bottom sludge in the Bay. Whereas the reclamation area, planned in the inner part of the Bay, had a fairly thick layer of contaminated sediment as compared to other parts, the dredging area required only an average of roughly 50-cm-deep dredging. However, the thickness of the layer to be removed by dredging was accurately and carefully identified to ensure the elimination of all polluted sediment, as well as to minimize extra dredging so as to save time and cost.

#### Adoption of Cutterless Suction Dredger

Since bottom sludge disturbance due to dredging could cause mercury elution, a dredging method was carefully chosen so as to minimize muddiness. A conventional suction dredger cuts into the sea bottom at the suction mouth and then pumps up sediment to be removed. The sediment disturbance by the cutter causes muddiness. To reduce the muddiness substantially, a suction dredger without a cutter was developed specially for sediment dredging in Minamata Bay. Since the cutterless suction dredger had already been used with great success in sludge dredging, but on a smaller scale, in Tokuyama Bay and Yokkaichi Port of Japan, the use of this type of suction dredger was decided upon with a slight modification for the present work.

### Implementation and Execution Control

Sediment was dredged with four cutterless suction dredgers because only four of all existing cutterless suction dredgers were found to be applicable

to the present work with a slight modification. They differed from each other in their dimensions. The work area was divided into four portions for convenience. Then each of the above-mentioned four dredgers was assigned to a portion according to its properties.

All suction heads of these dredgers, including the mouth, were modified in advance as shown in Figures 5 and 6. Major modifications were as follows:

- a. The suction mouth shape was modified to suit Minamata Bay's sludge properties through the experiment with similar soft mud.
- b. Provisions were made for monitoring muddiness near the suction mouth. For this purpose, two kinds of systems were adopted: continuous measurement of turbidity and direct monitoring with an underwater TV camera. For turbidity measurement, continuous-type turbidimeters were attached to the suction head, with readings displayed in the dredger operation room. For visual check of muddiness, an underwater TV camera was mounted on the suction head, together with sight vanes positioned at constant intervals. Muddiness was checked on the TV monitor in the operation room on the basis of the view of the vanes. Besides, it was confirmed in advance through the model experiment that the vane visibility distance was correlated with turbidity. These two systems enabled the dredger operation in the operation room to check muddiness around the suction head and thereby take the necessary measures such as slowing down dredging speed.

Procedures to minimize extra dredging were as follows:

- a. Prior to dredging, submarine topography and sediment thickness were accurately measured for the dredging area.
- b. Submarine topography after ideal sediment removal without any extra dredging was expressed with contour lines.
- c. Since equal-thickness dredging was not technically feasible, a certain area was to be dredged to a uniform level; therefore, the dredging area was divided, in 30-cm units of thickness to be removed on the basis of the above-mentioned contour lines, into segments in which dredging to a uniform water depth would eliminate at least all subject sludge.
- d. To ensure high precision, enhance efficiency, and monitor dredging conditions, dredgers were furnished with various sensors, whose data were processed via microcomputer and displayed on the monitor screen in the operation room.

The major data obtained through the above operation management system, based on the measurements of various sensors loaded on each dredger, as well as the basic principle to obtain these data, were as follows:

- a. Dredging thickness. The suction mouth was on the side of the suction head, which swung left and right while pumping sediment. Therefore, echo sounders were installed on both left and right sides of the head to determine the dredging thickness from the difference between the

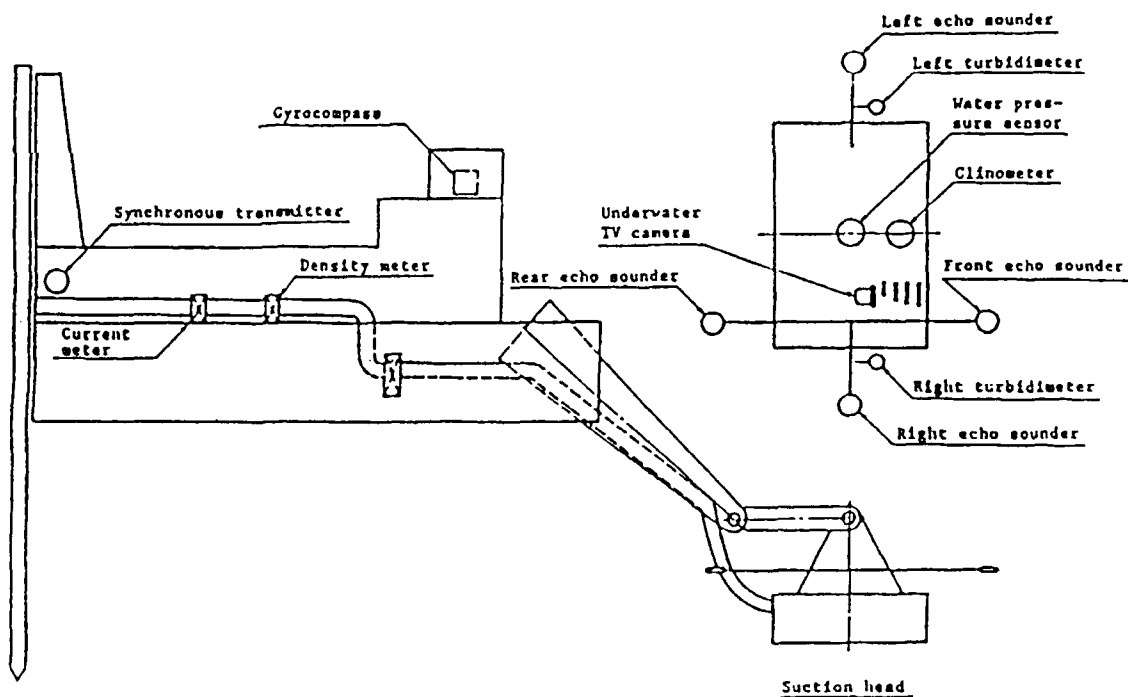


Figure 5. Cutterless suction dredger sensor locations

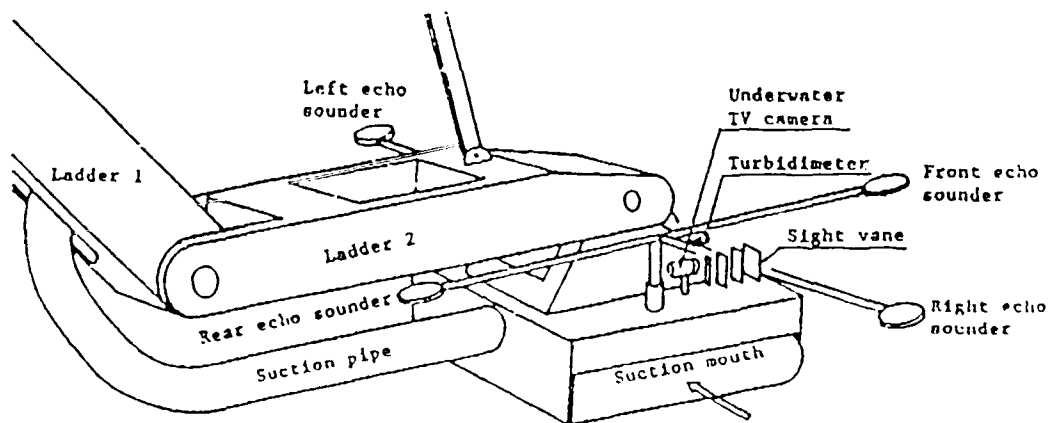


Figure 6. Suction head

readings of the two sounders. Since the inclined head gave the distorted measurement, a clinometer was also attached to the head to correct the resulting thickness data.

- b. Submarine topography before and after dredging. The dredger moved forward while swinging its suction head and dredging. Therefore, sounders identical to the above-mentioned ones were also installed on both front and rear sides of the head to survey submarine topography before and after dredging. Errors due to the head inclination were corrected in the same manner as described in dredging thickness.
- c. Suction head position, swing speed, and swing direction. In addition to electric positioning equipment, the suction head was provided with a gyrocompass to measure the head position, swing speed, and swing direction.
- d. Dredged volume and mud concentration. To measure these data, a current meter and a density meter were installed in the dredger discharged pipe. Both meters were used to manage the effluent treatment system.

Resulting measurements, together with other necessary data for execution control, were processed via microcomputer onboard and displayed in real time on the monitor screen in the operation room. Figures 7 and 8 show an example display and the summary of dredging work, respectively.

The discharge pipe was also improved to prevent sludge exposure to air and sunlight, both of which promote methylation of inorganic mercury in sludge. In addition to this improvement, the discharge outlet in the reclamation area was submerged in water, with the discharged sludge kept underwater during work.

### Effluent Treatment

#### Effluent Treatment Planning

The ordinance issued by the Prime Minister's Office stipulates that effluent from the land reclaimed with harmful earth/sand must not contain mercury exceeding 0.005 ppm. Since a mercury analysis takes a lot of time, turbidity, which is correlated with mercury concentration and can be measured in real time, was also monitored as the quickest information for efficient operation of the effluent system.

The following points were kept in mind in designing effluent treatment:

- a. To increase natural sedimentation in the reclamation area, the effluent flow distance was maximized by commencing reclamation from the innermost portion and by providing partition cofferdams in the area.
- b. Precipitation in the reclamation area was estimated on the basis of past data, and then the result was incorporated into the effluent treatment plan.

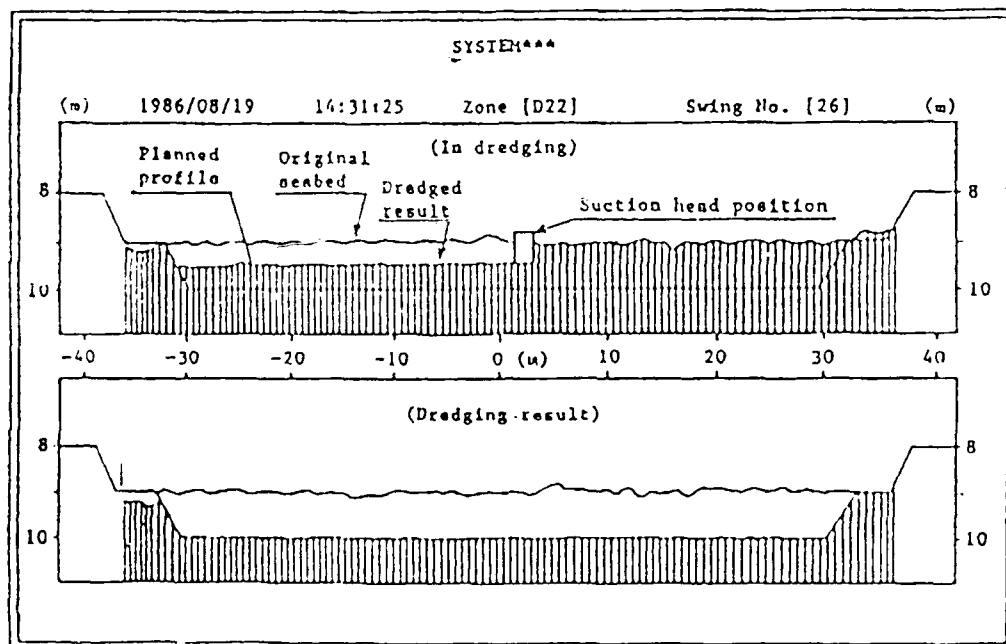


Figure 7. Example display on monitor screen

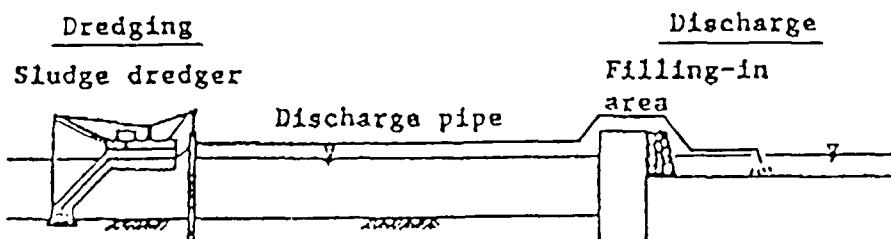


Figure 8. Dredging work

- c. Before discharge, effluent was to pass through the effluent treatment facility, which was composed primarily of a mixing tank, flocculant mixer, flocculation tank, settling tank, and rapid filter.
- d. Since effluent treatment, unlike dredging, can be controlled even at night, 24-hr treatment was designed.

#### Treatment Procedure

Sludge discharged into the reclamation area had to be kept underwater at all times to prevent direct exposure to air and sunlight. Water depth was checked every morning to ensure at least 50 cm as a general rule.

Since rainwater inflow from the existing land into the reclamation area lowers the effluent treatment efficiency, a side ditch was installed between the land and the reclamation area to divert rainwater flow from the land.

With these points kept in mind, effluent was treated in the following manner:

- a. After natural sedimentation in the reclamation area, supernatant water was first subjected to water quality testing to determine the need for flocculant addition and, if needed, the appropriate amount.
- b. Water was first sent to the mixing tank, where a flocculant was added if necessary, then to the flocculation tank, and finally to the settling tank, where flocs settled.
- c. Resultant effluent flowed into the monitoring tank for water quality testing.
- d. If the discharge criterion was exceeded, effluent was sent back to the rapid filter for thorough purification.

It was planned that if muddiness exceeded the supervisory standard, effluent discharge would be suspended. However, so far muddiness remained well below the standard, so no hindrance occurred to the operation.

#### SLUDGE CONFINEMENT

Sludge discharged into the reclamation area required covering with mountain soil and other good-quality earth/sand for confinement. Since sludge was high in the proportion of fine particles, extremely high in water content, and low in bearing capacity, earth-covering work would be inefficient and almost impossible if conducted over such sludge as it was. To increase bearing capacity sufficiently for subsequent earth-covering work, the sludge surface was subjected to the following two processes:

- a. The entire reclamation area was covered with a sandproof membrane to disperse the concentrated load to be imposed.
- b. Sirasu (volcanic ash earth/soil of low specific gravity, locally produced), which generates strength with light weight, was sprinkled

over the sludge to the thickness of 80 cm because of the bearing capacity consideration.

These processes, always carried out underwater (50 cm or more deep) to prevent sludge exposure to air, imparted the required bearing capacity to the sludge surface, making smooth and efficient earth-covering work possible. After water in the reclamation area was drained, good-quality mountain soil was sprinkled over the sludge and leveled for complete confinement.

## SUPERVISION

### Monitoring Plan and Results

A thoroughgoing monitoring plan was developed to prevent a secondary public nuisance due to sediment disturbance and dispersion with work, or to exudation of harmful substances from the reclamation area. In response to resident anxiety as to work safety, continuous monitoring was planned for water quality and fishery product contamination.

In the water quality studies (Table 1), basic monitoring points were provided along the work area boundary to prevent work influence beyond that area. Subsidiary monitoring points were also provided between the basic monitoring points and the current working points to predict water quality at the basic monitoring points for expeditious assessment of work propriety. On the other hand, in the fishery product contamination studies (Table 2), periodic sampling and analysis were conducted, together with fish culture experiments in Minamata Bay and plankton investigation, to ensure that work implementation would not pollute the aquatic life in the Bay. The locations of the water quality monitoring points and the sea-farming facility for fishery product monitoring are shown in Figure 3.

These monitoring practices were carried out under the direction of the Kumamoto Prefectural Government. To confirm work safety from an objective standpoint, the Minamata Bay Public Pollution Control Work Supervisory Committee was established in December 1976 as an advisory organization to the Prefectural Government. The Committee consists of eight experts, four staff members of administrative agencies concerned, three members of the Prefectural Assembly, and ten resident representatives. Committee meetings are open to the public as a general rule.

Water quality testing in accordance with the monitoring plan revealed that turbidity, hydrogen ion exponent, chemical oxygen demand, and dissolved oxygen showed variations probably attributable to natural environmental changes (rainfall, red tide, etc.) but that mercury concentration and all other items remained below determination limits or did not exceed supervisory standards. Work safety was thus confirmed.

None of the fish sampled outside the work area exceeded the supervisory standard for total mercury concentration. Continuous investigation into total mercury concentration changes in fishery products in the work area revealed no noteworthy changes suggestive of work influence.

TABLE 1. PLAN FOR WATER QUALITY MONITORING

Monitoring Points	No. of Monitoring Points	Check Items and Frequency	Supervision Standards	Assessment Method
Basic Monitoring Points (M)	4	<p>Total mercury concentration and turbidity</p> <p>During dredging: 3 times/day (9:00, 13:00, 17:00)</p> <p>During other work: 2 times a day (13:00, 17:00)</p> <p>Living environment-related items</p> <p>Hydrogen ion pH      Daily</p> <p>Chemical oxygen demand      (13:00)</p> <p>Dissolved oxygen      (13:00)</p> <p>Normal hexane extracts</p>	<p>Total mercury concentration 0.0005 ppm max</p> <p>Hydrogen ion pH 7.8 - 8.5</p> <p>Chemical oxygen demand 3 ppm maximum</p> <p>Dissolved oxygen 5 ppm minimum</p> <p>Normal hexane extracts not detected</p> <p>0.5 ppm max</p> <p>Arsenic and lead: for reference</p> <p>Turbidity 7 ppm</p>	<p>Weekly average must not exceed supervisory standard</p> <p>(Weekly average calculated daily for each monitoring point must not exceed supervisory standard)</p> <p>Highest value must not exceed supervisory standard</p>
Subsidiary monitoring points (S)	3	<p>During dredging, provided as necessary for current dredging area</p> <p>Arsenic      Weekly</p> <p>Lead      Weekly</p> <p>Turbidity 5 times/day (every 2 hr after work commencement)</p>		
Peripheral area		Abnormal muddiness, etc., with monitoring boats		

(Continued)

TABLE 1. (Concluded)

Monitoring Points	No. of Monitoring Points	Check Items and Frequency	Supervision Standards	Assessment Method
Underwater monitoring points (W)	5	Total mercury concentration Chlorine ion	Total mercury concentration  Not detected 0.0005 ppm max  Chlorine ion: for reference	Highest values must not exceed supervisory standard
Reference investigation 1 (R)	3	Total mercury concentration	Weekly	Supplementary investigation (for reference)
Reference investigation 2 (M-2, S-2)	2	Chemical oxygen demand, nutrients salts (phosphorus as phosphoric acid, nitrogen as ammonia, nitrous acid and nitric acid) and chlorine ions	Twice/month	
Reference investigation 3 (MR-5, MR-6)	2	Total mercury concentration, turbidity, hydrogen ion pH, chemical oxygen demand, dissolved oxygen	Weekly	

TABLE 2. PLAN FOR SEAFOOD CONTAMINATION MONITORING

Investigation Subject		Check Items, etc.	Remarks
Fishery products	General sea	Major species, total mercury concentration, seasonally (when total mercury concentration exceeds 0.4 ppm, methyl mercury is to be checked)	Supervisory standards Total mercury concentration: Methyl mercury: 0.3 ppm max Assessment method Average by species must not exceed supervisory standards
	Work area	Major species, total mercury concentration, monthly	Compared with prior investigation results
Plankton	General sea area and	Zooplankton, total mercury concentration, 6 times/year	Compared with prior investigation results
Fish culture	Work area	Porgy and opaleye, total mercury concentration, 3 times/months  From nonpolluted fish cultured in a fish-farming facility, 10 are sampled and analyzed every 10 days	Compared with prior investigation results

## Confirmation of Sediment Dredging Completion

It was determined in advance that sludge dredging would be adjudged completed if the average mercury concentration of four grid points of a mesh was below 25 ppm in each of the meshes (200 m-interval meshes as a general rule) established to determine the dredging area and the investigation points of mercury concentration.

In December 1987, just after completion of dredging work, the Kumamoto Prefectural Government sampled and analyzed sediment in the dredging area and its peripheral area to determine mercury concentrations in individual meshes (Figure 9). According to Figure 9, the highest concentration was found to be 8.75 ppm, far below the criterion of 25 ppm. In addition, the comparison between the results in Figure 2 and Figure 9 shows the great improvement of the Bay environment after the dredging work. This finding was reported on February 26, 1988, to the 60th Supervisory Committee meeting, where completion of Minamata Bay mercury sludge dredging was formally confirmed.

### CONCLUSION

Sediment dredging work, which was the main part of the whole disposal work planned, had been successfully completed in December 1987. The completion without the occurrence of any new public nuisance relieved the residents of much anxiety. Since 1977, disposal work in Minamata Bay has been carefully carried out with environmental control. This is natural in recognition of a great fear of dealing with the special matter of mercury-contaminated sediment. Thus, it was necessary to develop and improve the working method and equipment because of the special mercury properties.

Disposal work is now smoothly approaching completion this March with the final act of earth-covering work, after about a 10-year struggle against Minamata disease.

In this port, the so-called "Marine Town Project," a series of waterfront development activities was planned and actively started for local revitalization. It is hoped that by taking advantage of the coming completion of the disposal work, this revitalization would be well advanced with the effective utilization of the sludge-reclaimed land.

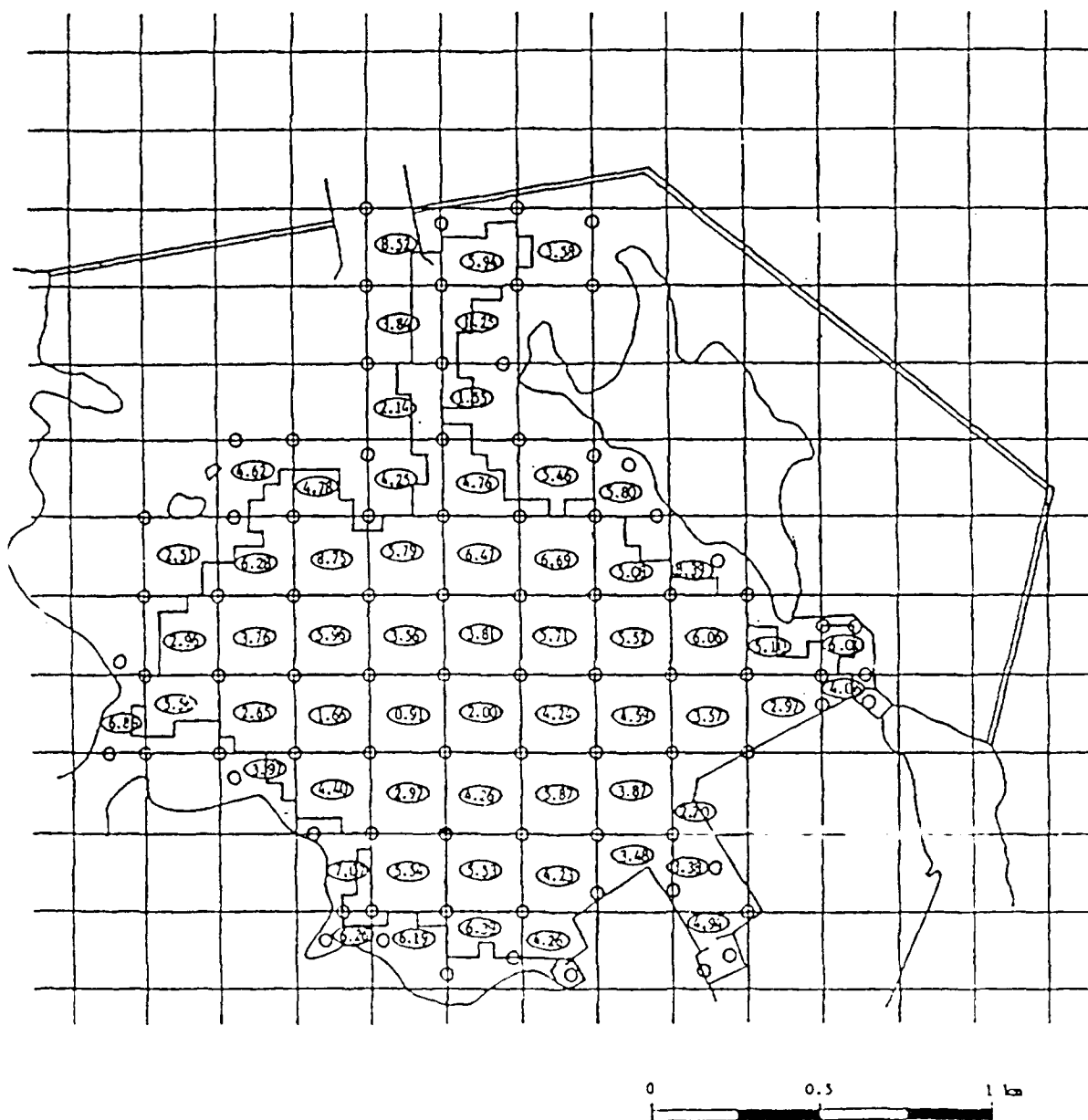


Figure 9. Mercury concentration distribution after dredging work

**RESTORATION OF LAKE SHIBAYAMA****M. Nakamura**

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**ABSTRACT**

The pollution of lakes in Japan is serious in all parts of the country. Although Lake Shibayama is a small one, or a swamp, its pollution is not treated lightly, because many people visit the hot spring spa on its shore. Pollution studies started in 1981; the work on the restoration project was actually begun in 1986. As a restoration technique, the dredging of sediment was employed. This paper describes the pollution studies and the management of dredged material activities.

**TOPOGRAPHICAL BACKGROUND**

Lake Shibayama is situated in the northeastern part of Kaga City, 40 km (southeastern direction) from the capital city of Prefecture Ishikawa, Kanazawa (Figure 1). It is one of the three Kaga lakes including Lake Kiba and Lake Imae (Figure 2).

It is an inland-sea lake born inside a sand dune. The national reclamation work aiming to spread farmland in this area started in 1952 and changed the topographical forms of the three lakes. Lake Kiba was isolated, Lake Imae disappeared, and Lake Shibayama lost two-thirds of the whole lake area by landfill. As a result, the lake water which flowed previously from Kakehashi River to the Nippon Sea via Kushi River had a new flow line connecting directly to the Nippon Sea.

Lake Shibayama has a surface area of 192 ha and a mean depth of 2 m. Since the lake has become important in river conservation, it is now administrated as a secondly graded river.

Lake Shibayama is located in the Kaga hot spring resort and has a spa on its shore. It is regarded as an important lake for sightseeing, agricultural water usage, inland fishery, and wildlife habitat. The area between the lake and the Nippon Sea was the ancient famous battlefield (Shinohara's) in the Genji and Heike Wars. Around the site remain many sad stories such as the "Head washing pond," where Sanemori Saito, General of Heike, washed his neck.



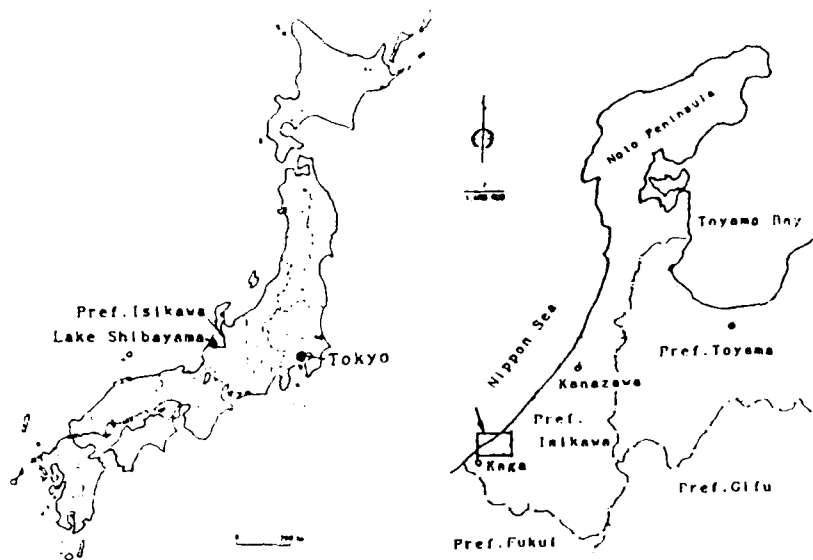


Figure 1. Location of Lake Shibayama

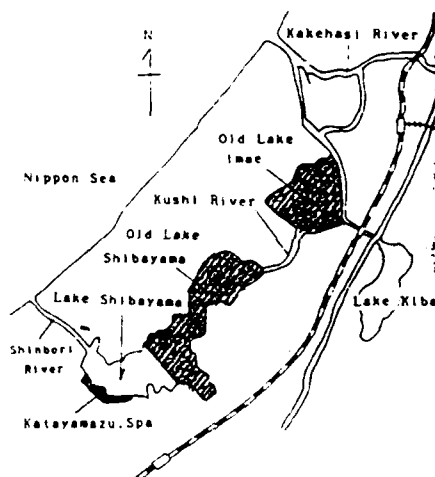


Figure 2. Location of the three Kaga lakes

#### ENVIRONMENTAL BACKGROUND

The water pollution of the lake began to increase in 1965 as a result of urbanization of its surroundings and accelerated the erection of sewage facilities, which resulted in no further marked pollution for a while. However, the eutrophication increased owing to the release of nutrients from sediment that had accumulated on the lake bottom. This process is a fatal phenomenon of a closed water area.

The Prefectural Government started to implement the lake restoration project in 1986, which consisted of the removal of sediment and the reduction of internal loading.

The water area near the lake was acknowledged as an A-rank category in 1974. As previously mentioned, the rank is due to the highly needed

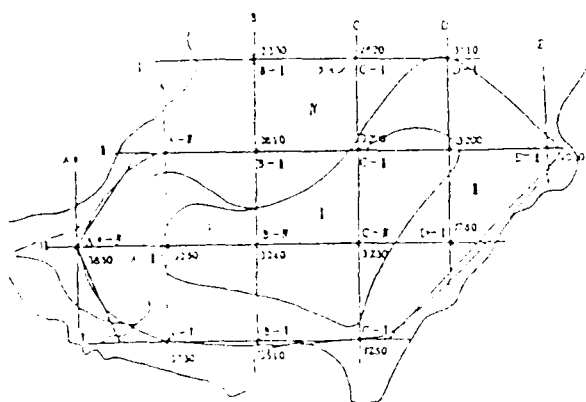
protection of lake environments and to the significant evaluation of the important sightseeing resources of the Katayama spa. But because of the difficulty of attaining the desired standard within a short time, the lake is now recognized as a B-rank category for the time being.

The downstream area of the Iburibas'ii River and the whole area of the Yokkaichi River were acknowledged as a B-class category. The environmental standard of the lake is applied to the Shinbori River, newly excavated for an outflowing line, because of the short length and the antitide floodgate erected at its estuary.

### POLLUTION STUDIES

The environmental protection division of the Prefectural authorities started to carry out pollution studies related to the eutrophicated conditions of Lake Shibayama in 1981. The river engineering division entrusted our sediment management association with various investigations, including water and sediment surveys, analysis of them, and planning of sediment removal work.

From measurements of ignition loss, chemical oxygen demand (COD), total nitrogen, and total phosphorus, which are of special concern in lake pollution, maps of their plane distributions were made, as shown in Figures 3 and 4.



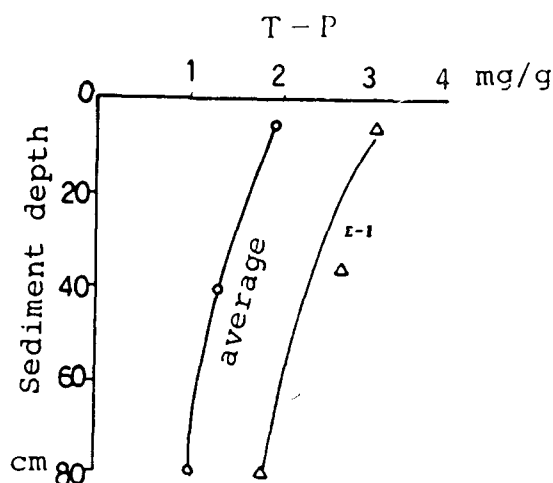


Figure 5. Vertical profile of T-P

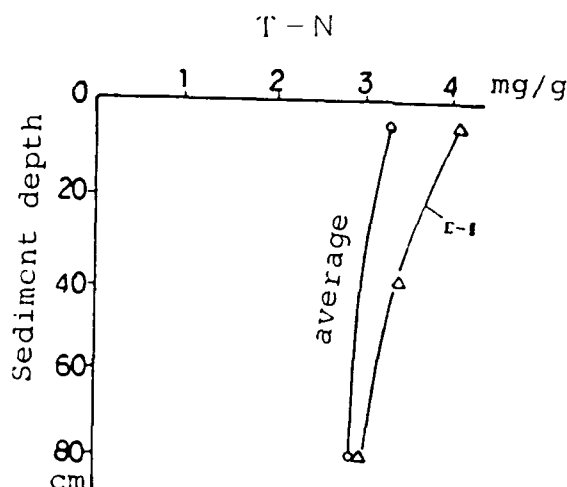


Figure 6. Vertical profile of T-P

#### OUTLINE OF WORK

Figure 7 shows the total dredging areas and disposal site areas. Figure 8 illustrates the yearly completed sections, as summarized in Table 2.

Considering the noisy effects to the spa, the dredge with an electric pump motor was adopted in 1986 and 1987 and the one with a diesel engine in 1988. The noise level at an inn nearest to the noise source was about 55 db, because a special silencer was attached to the diesel engine. Therefore, no complaints were voiced from people at the spa. The dredged material was conveyed directly to the disposal sites, and the spill water was discharged after sedimentation with flocculants. Figure 9 shows a flowchart of the work.

#### Disposal Sites

As shown in Figure 7, the dredged material was disposed in the agricultural paddy fields northwest of the lake. The disposal area in 1986 was 200,000 m<sup>2</sup> located in farmland on the right bank of Shinbori River at the Ikiri division of Kaya City. The embankments had a total length of 6,670 m, and foot paths between the rice fields of 5,840 m. A section of embankment is shown as Figure 10.

The disposal area in 1987 was 190,000 m<sup>2</sup> located in farmland on the left bank of Shinbori River at the Shinohara, Shinohara-Shin, and Ikiri divisions of Kaya City. The planned disposal area in 1988 was 100,000 m<sup>2</sup> in farmland along Hokuriku Highways on the right bank of the Shinbori River at Ikiri Town.

#### Disposed Thickness

Considering the working efficiencies of cultivators after sun drying, the disposed thickness was 15 cm in 1986, 30 cm in 1987, and 30 cm in 1988.

TABLE 1. SEDIMENT PROPERTIES

Parameter		Sediment Depth (cm)		
		Upper 0 ~ 10	Middle 20 ~ 30	Lower 40 ~ 50
Water content, %	range	93.4 ~ 177	130 ~ 200	78.3 ~ 188
	average	151	164	138
Specific gravity	range	24.81 ~ 26.08	2.525 ~ 2.624	-
	average	2.562	2.577	-
Unit vol. weight (grain size), g/m <sup>3</sup>	range	1.19 ~ 1.35	1.19 ~ 1.32	-
	average	1.18	1.27	-
Coarse sand	range	0 ~ 0.10	0.0	-
	average	0.04	0.0	-
Fine sand	range	0 ~ 8.0	0 ~ 5.8	-
	average	2.5	1.7	-
Silt	range	66.2 ~ 82.8	30.4 ~ 87.7	-
	average	73.6	52.4	-
Clay	range	13.7 ~ 33.8	12.3 ~ 62.7	-
	average	23.9	45.9	-
Ignition loss	range	11.6 ~ 14.6	11.2 ~ 14.8	87.7 ~ 12.4
	average	13.3	12.4	11.4
COD, mg/g	range	44.1 ~ 60.2	43.1 ~ 69.0	25.4 ~ 52.1
	average	51.3	50.2	43.4
Sulphide, mg/g	range	0.04 ~ 1.30	0.09 ~ 4.10	0.04 ~ 5.30
	average	0.29	0.72	0.46
T-N, mg/g	range	2,330 ~ 4,030	2,280 ~ 4,350	1,820 ~ 3,420
	average	3,293	3,151	2,821
T-P, mg/g	range	1,370 ~ 2,510	802 ~ 2,708	604 ~ 1,780
	average	1,908	1,317	965
T-C, mg/g	range	33,600 ~ 47,100	25,700 ~ 38,300	19,900 ~ 35,400
	average	37,294	32,731	29,613

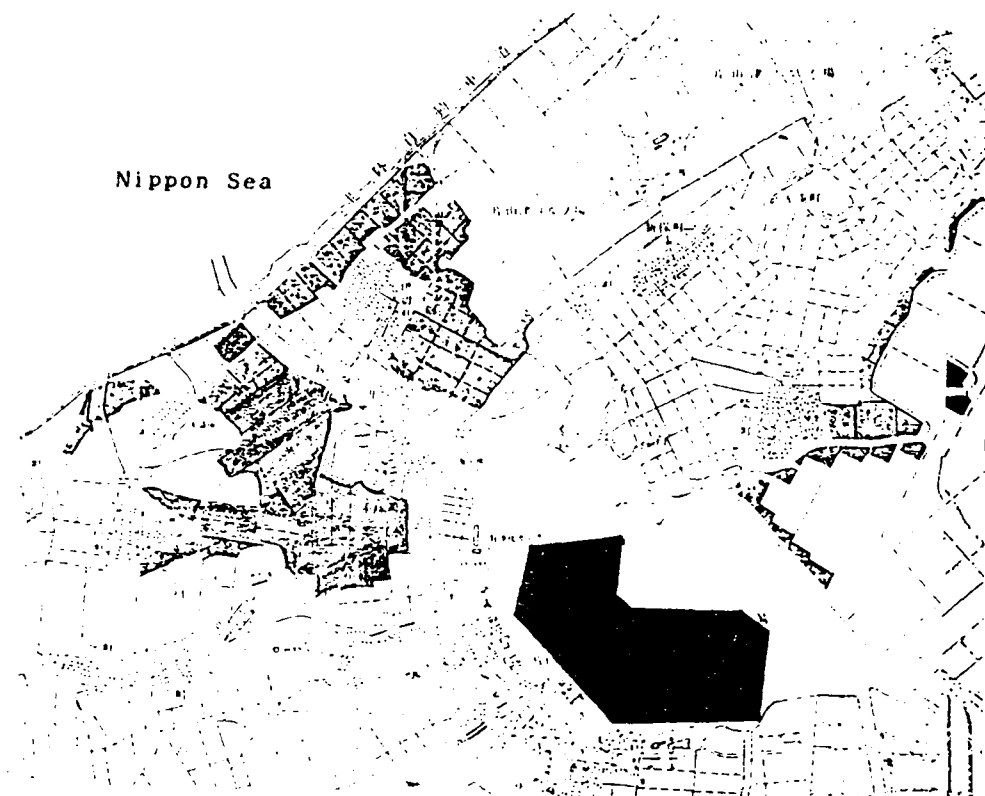


Figure 7. Total dredging and disposal site areas

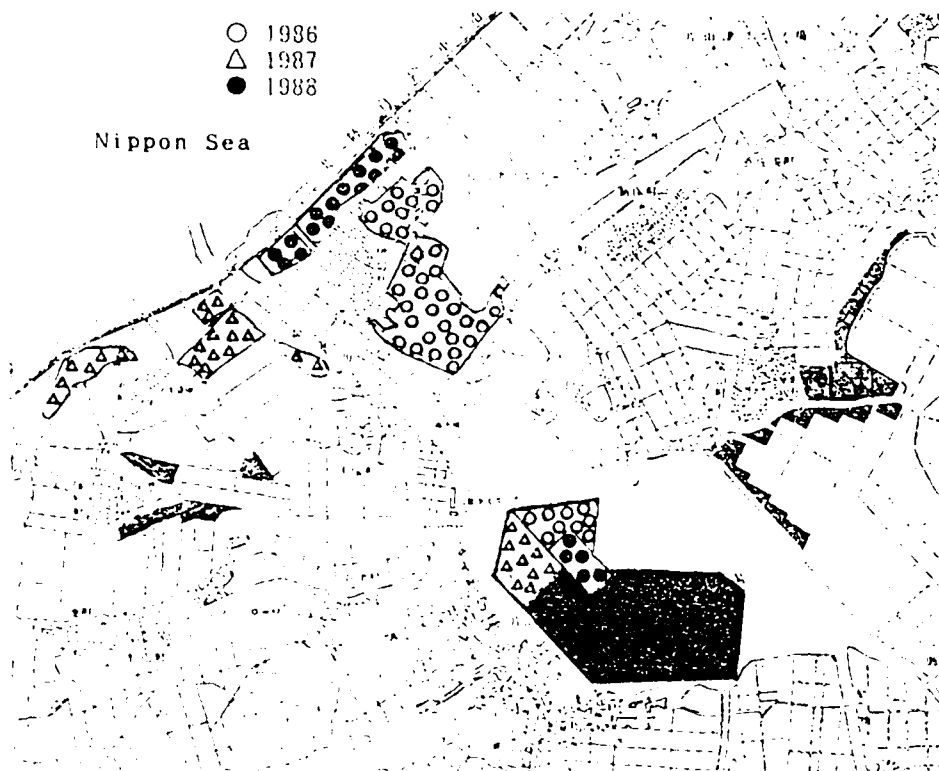


Figure 8. Yearly completed sections of the dredging and disposal areas

TABLE 2. YEARLY COMPLETED WORKS

Parameter	1986	1987	1988	Total	Entire Plan
Dredging area, m <sup>2</sup>	61,600	96,000	60,000	217,600	850,000
Removal depth, m	0.5	0.5	0.5	0.5	0.5
Removal quantity, m <sup>3</sup>	30,800	48,000	30,000	108,800	425,000
Finished percentage	7.2	11.3	7.0	25.5	100

### Dredging

Considering removal accuracies and generated turbidities, the dredge with a cutterless pump (E350 ps, D600 ps) was adopted for thin-layer (0.5 m) dredging. Especially for the purpose of removing efficiently a suspended layer just overlying sediment, the dredging was conducted as a two-time cutting method. The effective swing width was 25 m, and the practical width including lap allowance was 30 cm.

### Hydraulic Conveying

The distance from the dredge to the disposal sites was 2,070 m in 1986; between 2,200 and 3,200 m in 1987; and an average of 2,800 m in 1988. As these distances exceed the practical limit of a 350-ps dredge, an intermediate pump of E350 ps was installed. The piping system was arranged so that floaters were set on the seaside, and the pipe supports with two heights ( $h = 0$  and  $h = 1$  m) were equipped on land. The following tabulation shows the various boats used in this work.

Boats	No.	Capacities
Dredge	1	E350 ps
Cutterless	1	D600 ps
Booster pump boat	1	E350 ps
Anchor pulling-up boat	1	60 ps, 3 t lifting
Traffic boat	1	3 t, D10 ps

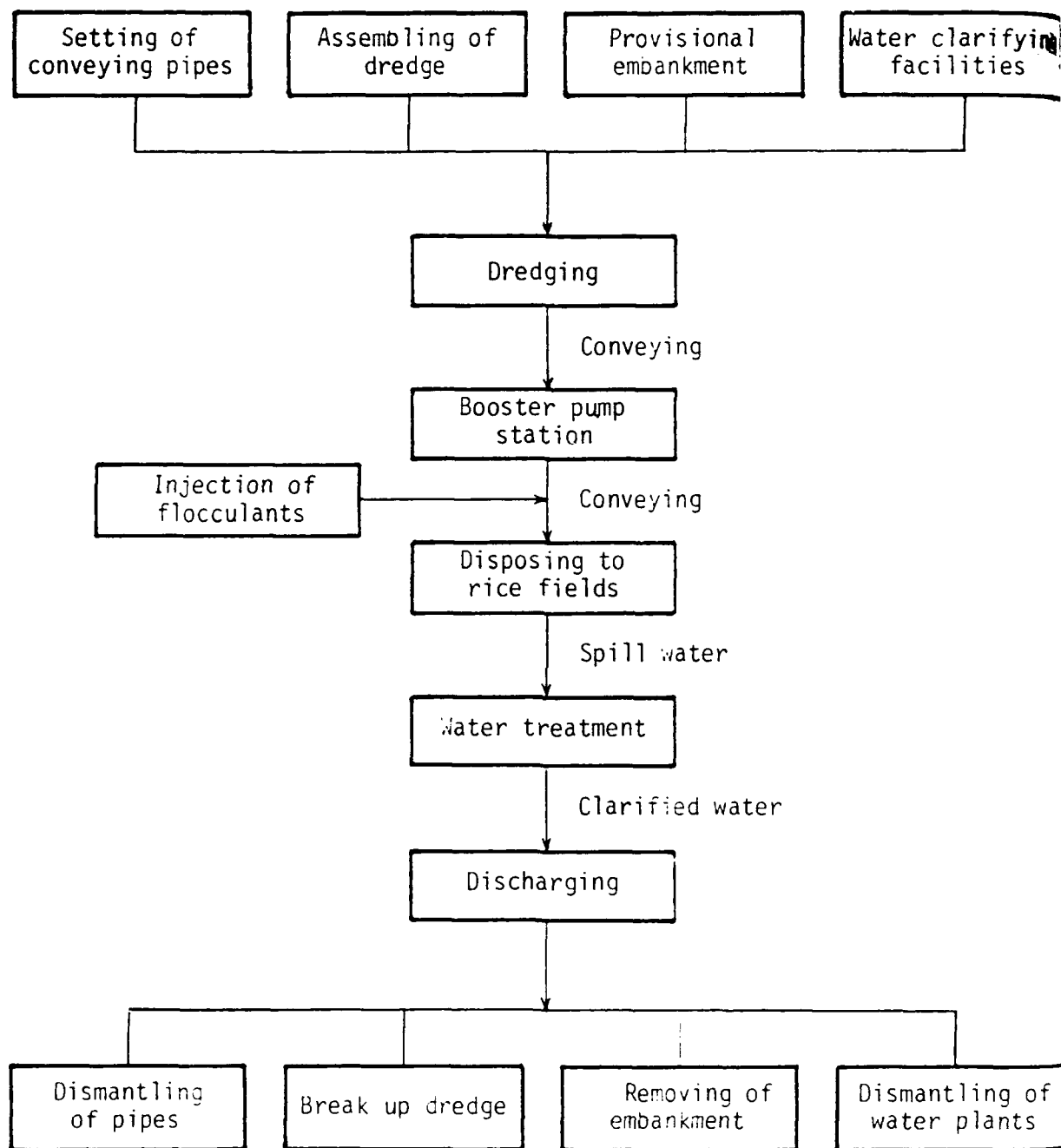


Figure 9. Project operations activities

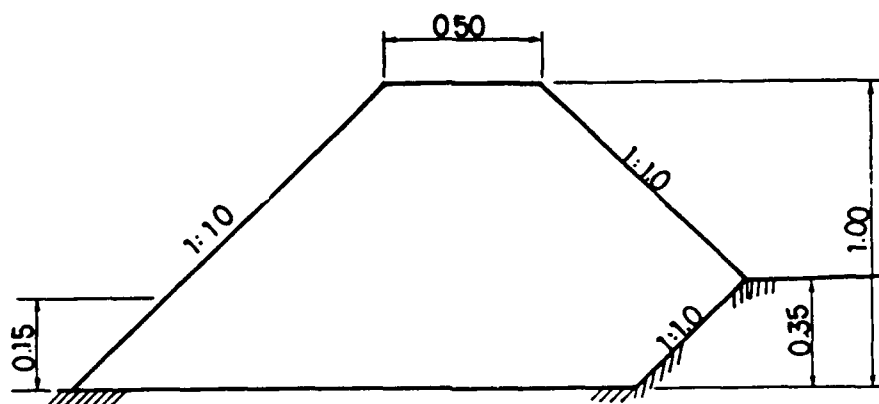


Figure 10. Section of embankment

### Treatment of Spill Water

#### Spill-Water Quality

The effluent qualities standards in Table 3 are applied to the basin adjacent to the lake and the Shinbori River according to the regulations of Prefecture Ishikawa. The spill-water quality was decided as follows based on the effluents standards:

SS: 70 mg/l on an average  
100 mg/l at maximum

pH: 5.8 ~ 8.6

TABLE 3. EFFLUENT STANDARDS APPLIED TO THE SHIBAYAMA BASIN

Shinbori River Area Factories and Businesses (1974)	Permissible Limits					
	BOD		COD		SS	
	Ave.	Max.	Ave.	Max.	Ave.	Max.
Stock raising, foodstuff industry, hospital, refuse burning, urine facilities	80	120	80	120	100	150
Sewage end facilities	20	30	20	30	70	90
Others	60	80	60	80	80	120
Places having sewerage	20	30	20	30	70	90
Places having sewer- age projects	120	160	120	160	120	180

## Treatment

For the treatment of spill water, an agglomeration system was adopted considering the short and temporary nature of the work and the spill-water quality previously discussed. Figure 11 shows a flowchart for this system. The size of the settling pond was decided considering the retention time of influents, water surface loading, etc.

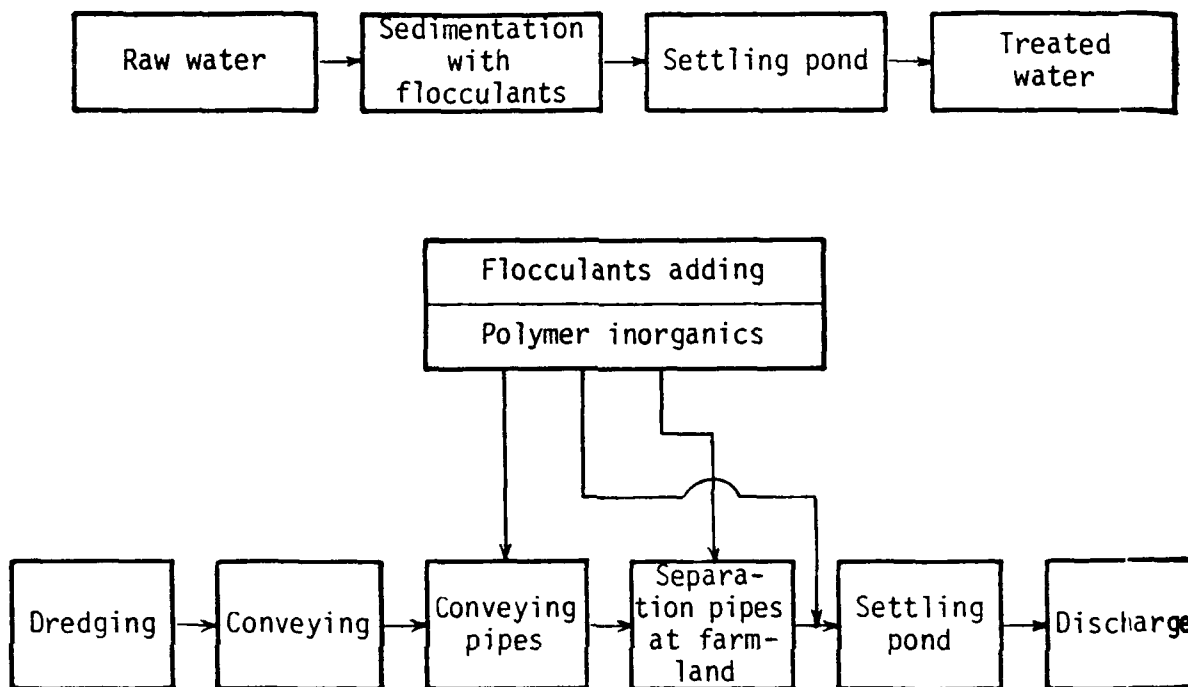


Figure 11. Agglomeration system for water treatment

## Installations for Water Treatment

Clarification of spill water consisted of two methods: an injection of polymeric flocculants into the conveying line, and a showering of inorganic sulfuric aluminum (sometimes mixed with polymer) at the settling pond. The quantities of medicines used are indicated in Table 4.

TABLE 4. ANNEXED MEDICINES

Method	Flocculants	Quantities Added
Pipe injection	Polymeric flocculants	40 g/sediment m <sup>3</sup>
Showering	Inorganic flocculants	80 g/dredged material m <sup>3</sup>
	Sulfuric aluminum	
	Polymeric flocculant	1.5 g/dredged material m <sup>3</sup>

The monitoring of discharged water pH and turbidities was conducted two times per day to control the running conditions by comparing to the annexed quantities.

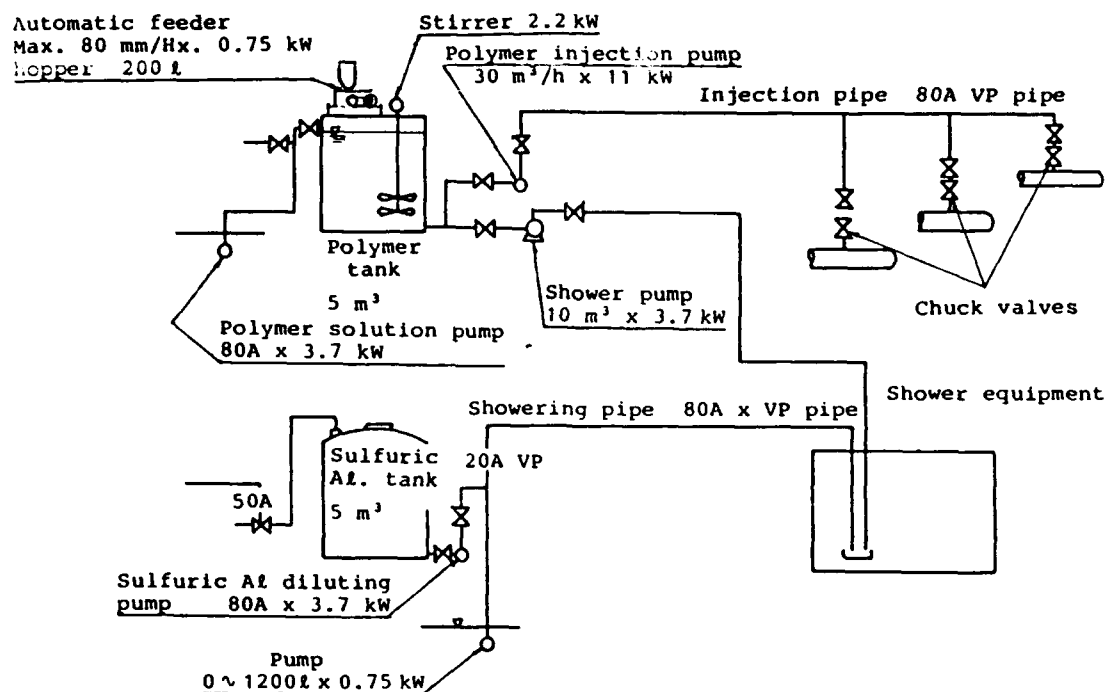


Figure 12. Flowchart of spill-water treatment

## Results of Treatment

As a result of appropriate controls, the spill-water quality satisfied the regulation standards. When the treatment was nearing completion, it was necessary to control the dredging intermittently.

## RESULTS OF RESTORATION

To see the effects of dredging it is important to observe a summer peak, which is a phenomenon generated by highly released quantities of nutrients from the sediment in summer. The concentrations of chlorophyll-a, T-P, and T-N in sediment were compared with the dredged and undredged areas in 1986. A significant improvement was not recognized at the time when the dredged areas occupied only 7.2 percent of the whole. It seems natural that the restoration effects should appear after the dredging of about 25 percent of the area. Therefore, it is thought that they will appear in the future.

## SUMMARY

This work was carried out for three years from 1986 to 1988. However, it occupies only 25.5 percent of the entire Environmental Improvement Project of lakes and rivers. Therefore, it is necessary to continue the work. The agricultural use of dredged material brought about a 30-percent increase in the rice crop by changing badly contaminated water and converting sterile land to fertile land.

#### ACKNOWLEDGMENTS

The author would like to express great gratitude to the people in the River Engineering Division of the Prefectural Government, in the Daishoji Engineering Office, for their cooperation in this work.

A PILOT STUDY OF DREDGING AND DISPOSAL ALTERNATIVES FOR  
THE NEW BEDFORD HARBOR, MASSACHUSETTS, SUPERFUND SITE

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ABSTRACT

Bottom sediments in New Bedford Harbor are contaminated with polychlorinated biphenyls (PCB) and heavy metals to the extent that the site is considered one of the Nation's worst hazardous waste sites and is being studied by the US Environmental Protection Agency (EPA) under the Federal Superfund program. At the request of EPA, the Corps of Engineers has evaluated the feasibility of dredging and disposal alternatives for the upper estuary of New Bedford, an area where PCB concentrations in the percent levels have been detected in the sediments. Between May 1988 and February 1989 a pilot study was performed as part of this effort. This study involved the evaluation of three hydraulic pipeline dredges with the contaminated sediments being placed in a confined disposal facility and a contained aquatic disposal cell.

This paper provides a comprehensive discussion of our approach and the results of this \$6.5 million effort. The study provided for a site-specific technical evaluation of the methods used which has allowed the Corps of Engineers to make recommendations to EPA which will be critical in their final evaluation of remedial alternatives for the site.

INTRODUCTION

New Bedford, Massachusetts, is a port city located on the northwest side of Buzzards Bay, approximately 55 miles south of Boston (Figure 1). Historically, New Bedford is known for its role in the development of the whaling industry in the 1800's. Today, the harbor is the home port to one of the largest commercial fishing fleets in the United States (Ebasco Services 1989).

The harbor is underlain by sediments containing elevated levels of PCBs and heavy metals including copper, chromium, zinc, and lead. PCB concentrations in the sediment range from a few parts per million (ppm) to over 100,000 ppm. PCB levels in harbor water have been measured in the parts per billion range (Weaver 1982).

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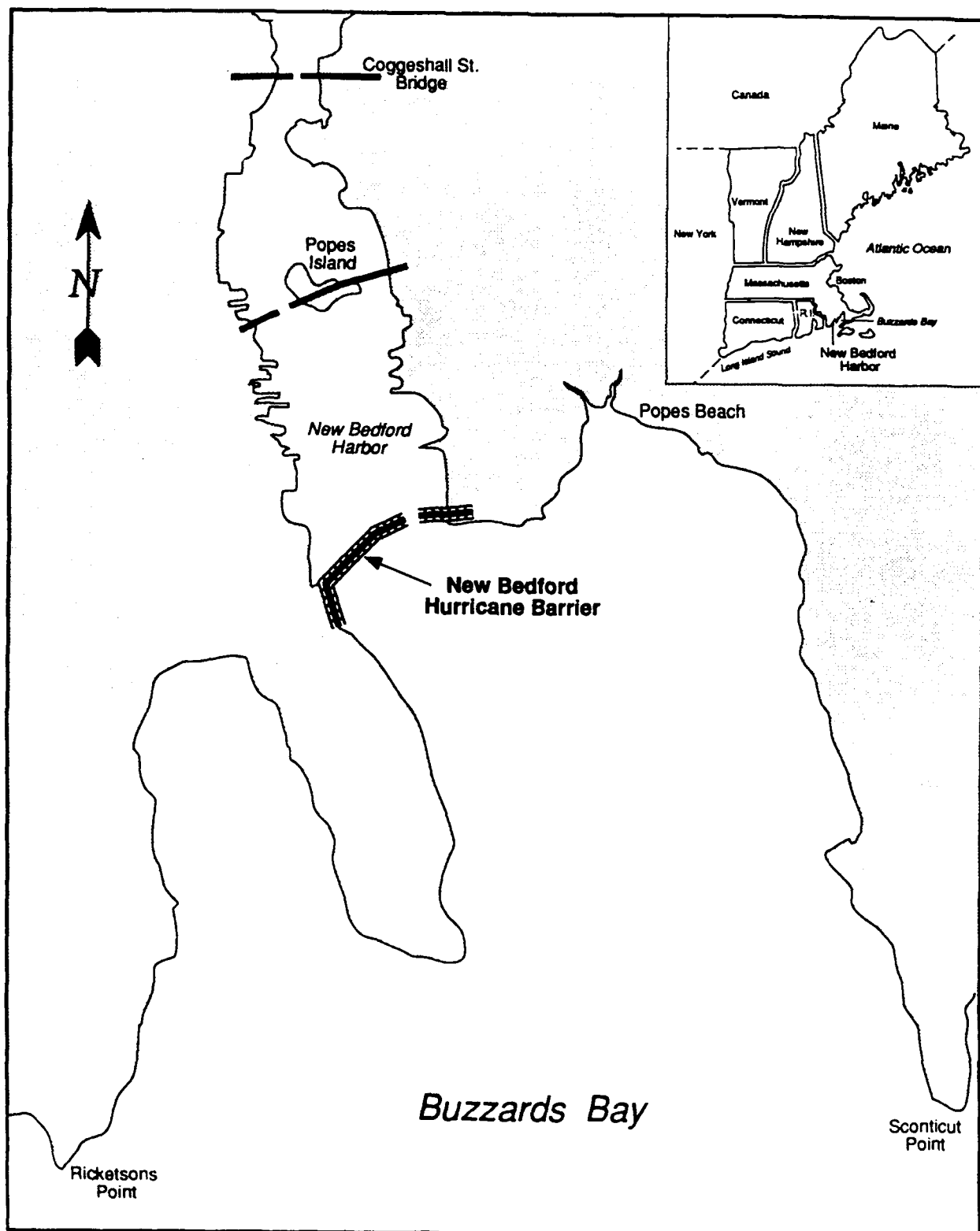


Figure 1. Outer New Bedford Harbor

The source of the contamination was two electrical capacitor manufacturers who were major users of PCBs from the time their operations commenced in the 1930's until 1977, when the US Environmental Protection Agency (EPA) banned the use of PCBs. These industries discharged wastewaters containing PCBs directly into the harbor and indirectly via the municipal sewer system (USEPA 1976).

In 1984 the EPA asked the Corps of Engineers (USACE) to evaluate the engineering feasibility of several dredging and disposal alternatives that have been proposed for the most northern portion of the site, referred to as the Acushnet River Estuary. This 200-acre area extends from the Wood Street Bridge south to the Coggeshall Street Bridge (Figure 2) and contains the highest levels of contamination. An Engineering Feasibility Study (EFS) was conducted at the USACE's Waterways Experiment Station which consisted of field data collection, literature reviews, laboratory studies, and modeling efforts, and led to the development of conceptual alternatives for dredging and dredged material disposal (Francingues et al. 1988). The pilot study, which is the subject of this paper, was an extension of the EFS. It allowed for the verification of design parameters after the laboratory studies were completed and prior to the final selection and design of a remedial action (New England Division, USACE 1989).

#### PILOT STUDY DESCRIPTION

The pilot study involved the evaluation of three types of hydraulic pipeline dredges and two disposal methods. Approximately 10,000 cu yd of sediment was removed, 2,900 cu yd of which was contaminated. Both use of a confined disposal facility (CDF) and contained aquatic disposal (CAD) were evaluated. Operations were extensively monitored to detect changes in water quality throughout the harbor that could be attributed to the dredging and disposal operations while gathering data to address the technical objectives of the study. These objectives were to

- a. Determine if dredges could effectively remove the contaminated sediment.
- b. Evaluate sediment resuspension and contaminant release at the point of dredging and during CAD.
- c. Determine if contaminated sediment could be contained in a CAD cell.

Dredging and disposal operations were conducted in a small cove adjacent to the channel in the upper estuary (Figure 3). PCB levels in the cove were 150 to 600 ppm in the top 6 in. of sediment and were not detectable below 2 ft. Water depths were 0.5 ft at low water with a tide range of approximately 4 ft. The sediment was an organic sandy silt. The shallow water and finegrained material are typical of a large portion of the upper estuary.

#### DREDGING EQUIPMENT

The three hydraulic pipeline dredges used during the study were a cutterhead dredge, a horizontal auger dredge know as a Mudcat, and a modified cutterhead dredge that has the cutterhead replaced with a Matchbox dredge head. This equipment was selected after a thorough evaluation by USACE

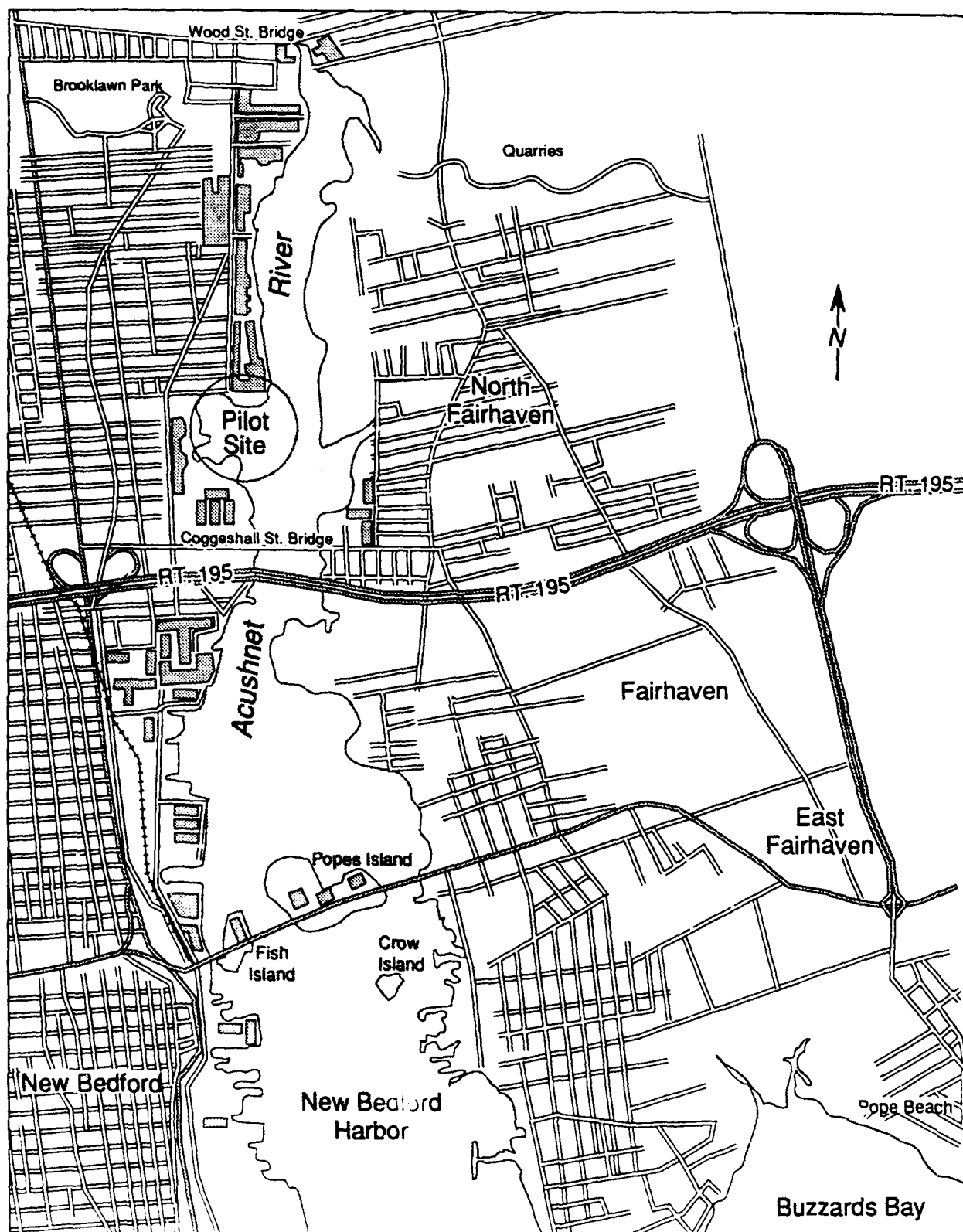


Figure 2. New Bedford Harbor and Acushnet River Estuary

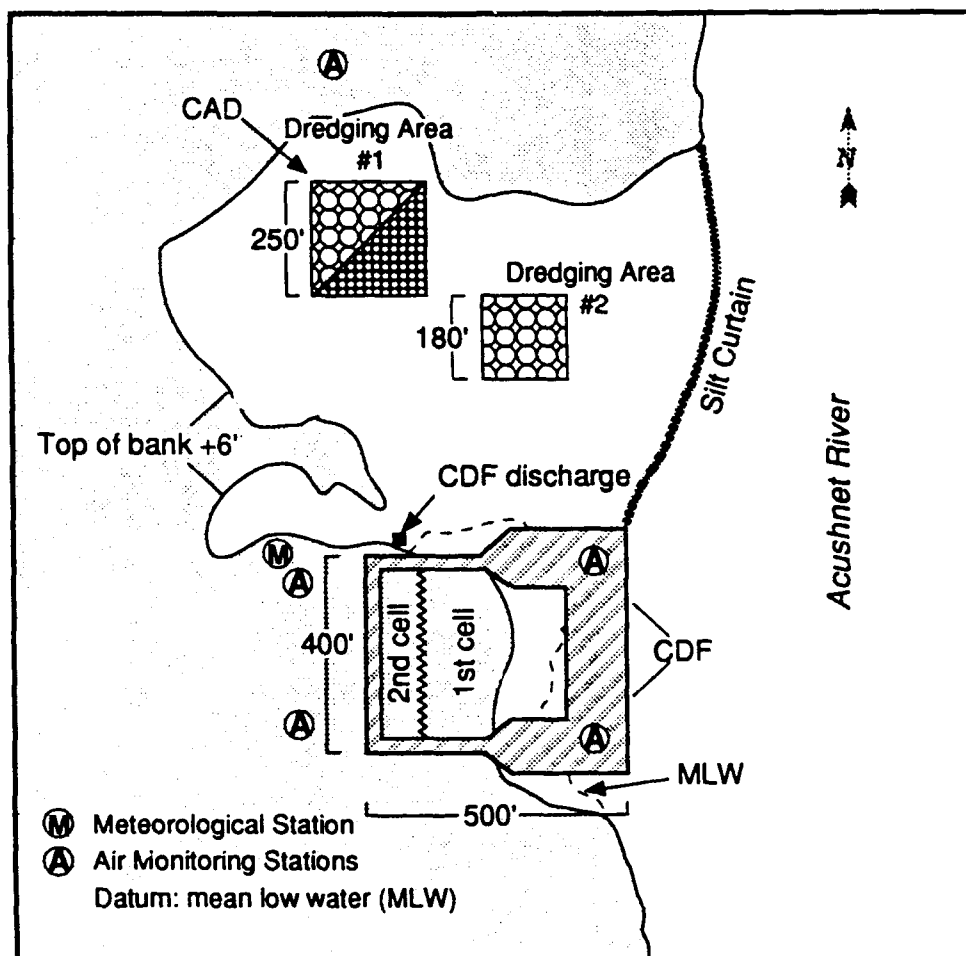


Figure 3. Pilot study site

personnel that considered a wide range of dredging equipment. The following factors were considered critical in selecting the dredging equipment:

- Ability to remove the layer of contaminated sediment while minimizing overdredging.
- Ability to minimize resuspension of sediment while operating.
- Ability to operate in the shallow water which is prevalent in the upper estuary.

The major operational differences between the dredges were their dredge heads and their method of moving through an area while dredging. Both the cutterhead and Mudcat dredges have a revolving dredge head that breaks up and agitates the bottom sediment. The Matchbox dredge head has no mechanical action and relies on the swing of the dredge and suction forces to move the sediment. The cutterhead and Matchbox dredges pivot on their stern spuds and dredge in a zigzag fashion while pulling on swing anchors. They advance by alternately raising and lowering the spuds at the end of a swing. The Mudcat

operates off a cable system, winching itself along in both forward and reverse.

During the course of the study, different methods of operating were experimented with while attempting to meet the project goals of removing the contaminated sediments while minimizing both over dredging and the resuspension of sediment. Operating parameters that were adjusted included swing speed, rate of advance, rotation of the cutterhead, and depth of cut.

#### DISPOSAL METHODS

The two disposal methods evaluated during the study were a confined disposal facility (CDF) and contained aquatic disposal (CAD). The CDF is a retention basin that was constructed on approximately 250,000 sq ft of area, half of which was located below the high water line. A granular fill dike was constructed around the perimeter of the CDF, and it was divided into two chambers by a sheet-pile wall. The dredged material slurry entered the primary cell where the majority of the solids settled out. The excess water flowed over a weir built into the sheet-pile wall where a cationic polymer emulsion was sprayed into the flow to promote additional settling of solids in the secondary cell prior to discharging the water back into the estuary. Approximately 2,200 cu yd of contaminated sediment was pumped into the CDF and subsequently covered with approximately 3,900 cu yd of clean dredged material.

CAD involved initially dredging a pit or cell in the bottom of the estuary. Approximately 700 cu yd of contaminated sediment was then discharged through a diffuser into the cell and subsequently capped with approximately 2,600 cu yd of clean material placed in the same manner. The area dredged during the filling of the CDF was used as the CAD cell. It was approximately 180 by 140 ft in size and 6 ft deep. A 0.5- to 1-ft layer of contaminated sediment and a 1- to 3-ft layer of cap material was placed in the cell.

USEPA's Environmental Research Laboratory in Narragansett, Rhode Island, assisted the USACE in designing and executing the monitoring program which consisted of physical, chemical, and biological evaluations of sediment, harbor water, leachate, and effluent from the CDF. The following were the program's major objectives:

- a. Monitor contaminant release pathways associated with the dredging and disposal operations.
- b. Monitor water quality throughout the harbor.
- c. Provide data in a timely fashion to assist in managing ongoing dredging and disposal operations.

Four monitoring stations were established throughout the harbor. They were located approximately 1,000 ft north of the pilot study cove, opposite the cove, at the Coggeshall Street Bridge and just upstream of the hurricane barrier. The stations were sampled prior to the start of operations to determine the existing ranges of specified physical, chemical, and biological response variables which occur within the system. The stations were subsequently sampled during the three phases of the project: CDF dike construction, dredging with disposal into the CDF, and dredging with CAD.

The Coggeshall Street Bridge station was the focal point of the monitoring effort due to the location (boundary between the more highly contaminated upper estuary and the less contaminated lower harbor) and the fact that water circulation is restricted at this point. At this station the flow was measured for each sampling event, and samples from six cross-sectional subareas were composited proportional to velocity. Equal portions of the five hourly composites were then combined to form one sample representing either the flood or ebb tide condition. Samples from the other stations were taken hourly at three depths. The five hourly composites were then combined into one sample for each station which represented the ebb or flood tide condition. The results of the preoperational monitoring are summarized below and in Table 1.

Seawater temperature	18.5° - 23.5° C
Salinity	22 - 33 ppt
Total suspended solids	6.4 - 10.2 mg/l (station 2)
	4.4 - 7.9 mg/l (station 1)

TABLE 1. PREOPERATIONAL MONITORING PERIOD - AVERAGE CONTAMINANT LEVELS

<u>Station*</u>	<u>Tide</u>	<u>Total PCB**</u>	<u>Cd**</u>	<u>Cu**</u>	<u>Pb**</u>
1	Ebb	1.69	0.33	6.8	4.1
2	Ebb	0.60	0.23	5.5	2.8
4	Ebb	0.12	0.15	2.7	2.2

\* Station 1 - approximately 1,000 ft north of work area.

Station 2 - Coggeshall Street Bridge.

Station 4 - Hurricane Barrier.

\*\* Reported in parts per billion.

Contaminant release pathways that were monitored during the operational phase of the study included leachate movement through the bottom and dikes of the CDF, effluent discharge from the CDF and airborne releases from the CDF, sediment resuspension and contaminant release at the point of dredging and at the discharge point during CAD, and movement of contaminants away from these operations.

## RESULTS

The dredges used during the pilot study were able to effectively remove the contaminated sediment while minimizing the amount of material removed. By making two passes over an area, the cutterhead and Matchbox dredges removed 1.1 to 1.5 ft of material leaving PCB levels of less than 10 ppm in the remaining sediment.

By slowing down the various operating parameters (swing speed, rate of advance, cutterhead rotation, etc.), sediment resuspension at the point of dredging was reduced. Resuspension rates and contaminant release at the point of dredging varied between the different dredges, but impacts 500 ft from the

point of dredging were minimal for all dredges. Average values for sediment resuspension rates, total suspended solids levels, and PCB levels adjacent to the dredge head are summarized in Table 2. The cutterhead dredge was recommended for future work in New Bedford based on the results of the pilot study.

TABLE 2. SEDIMENT RESUSPENSION AND CONTAMINANT RELEASE DURING DREDGING OPERATIONS

<u>Dredge</u>	<u>Resuspension Rate</u> <u>g/sec</u>	<u>Total Suspended</u> <u>Solids, mg/l</u>	<u>Total PCB</u> <u>ppb</u>
Cutterhead	12	82	7.0
Matchbox	46	319	2.6
Horizontal auger	329	1,610	54.9

- Notes:
1. Background levels for suspended solids and PCBs are less than 10 mg/l and 0.5 to 1.0 ppb, respectively.
  2. The resuspension rate is calculated using the following factors: water depth, length of dredge head, swing speed, and average suspended solids in the water column adjacent to the operating dredge head.
  3. Samples used to obtain these data were taken from a sampling device installed at the dredge head. Samples were drawn from six sampling ports positioned around the dredge head.

An array of 15 stations located around the dredges were sampled hourly while the equipment was operating. This monitoring effort was carried out to detect the movement of resuspended material and contaminants away from the point of dredging. Tidal currents within the cove were negligible (0.1 to 0.3 ft/sec), and a defined plume of resuspended material never developed. Suspended solids and contaminants were at background levels 500 ft from the operating dredges.

#### Contained Aquatic Disposal

The major questions relating to CAD involved the placement of contaminated sediment within the cell, the capping of this sediment with clean dredged material, and the sediment resuspension and contaminant release associated with the operation.

Hydrographic surveys indicated that a 0.5- to 1-ft layer of contaminated sediment was placed in the cell and capped with a 1- to 3-ft layer of clean dredged material. Sediment cores taken from the cell and analyzed for PCBs showed the capping operation to be unsuccessful, however, as elevated PCB levels were found in the surface sediment layers. The contaminated and cap material likely mixed together because of the position of the diffuser and the fluid state of the contaminated sediments. Because of the shallow CAD cell, the diffuser was located approximately 2 ft off the bottom, which may have disturbed the sediment in the area of the discharge. Capping operations also began immediately after disposal of the contaminated sediment without allowing

time for the material to consolidate. The physical characteristics of the contaminated and cap material are tabulated below:

	<u>% Fines</u>	<u>Water Content</u>	<u>Specific Gravity</u>	<u>Liquid Limit</u>
Contaminated	78	159%	2.46	123
Cap	79	117%	2.55	107

An array of 10 stations was established around the CAD cell to detect any suspended material or contaminants resulting from the operation. This monitoring effort showed that both suspended sediment and contaminant levels were elevated well above background and other phases of the pilot study. Table 3 summarizes suspended solids levels for a typical day of CAD.

TABLE 3. TOTAL SUSPENDED SOLIDS DURING A TYPICAL DAY OF CAD

<u>Sampling Event</u>	<u>Distance from Discharge, ft</u>	<u>Total Suspended Solids, mg/l</u>
1	100	31
	300	13
2	100	55
	300	26
3	100	49
	300	31
4	100	107
	300	78
5	100	179
	300	117

- Notes:
1. Samples were taken hourly with the first sampling event 30 min after the start of disposal operations.
  2. The values shown for total suspended solids represent the average of five individual samples.
  3. Background levels within the cove are generally less than 10 mg/l.

Several composite samples were formed daily from the five individual stations representing cross sections of the cove. These samples were analyzed for PCBs. The results show that PCB levels ranged from 2.5 to 31.8 ppb and averaged 13.4 ppb for the area 100 ft from the discharge point, and ranged from 1.5 to 15.3 ppb and averaged 6.8 ppb for the area 300 ft from the discharge point. Background levels in the cove range from 0.5 to 1.0 ppb.

### Confined Disposal Facility

Both the weir between the primary and secondary cells and the discharge from the facility were monitored during the operation. Samples were taken hourly and analyzed for total suspended solids. A daily composite was formed from these samples and analyzed for PCBs and metals. The results of these efforts are summarized in Table 4.

TABLE 4. CONFINED DISPOSAL FACILITY

<u>Total Suspended Solids Data, mg/l</u>			
<u>Location</u>	<u>Daily Average</u>	<u>Range</u>	<u>Number of Samples</u>
Weir	97	35-344	19
Discharge	75	27-152	15
<u>Dissolved PCB Data, µg/l</u>			
	<u>Mean</u>	<u>Range</u>	<u>Number of Samples</u>
Weir	1.9	0.6-4.3	12
Discharge	1.4	0.3-2.9	11
<u>Particulate PCB Data, µg/l</u>			
Weir	9.1	5.2-15.9	12
Discharge	10.7	5.0-19.2	11

These results indicate that the method used to predict the contaminant load in the CDF discharge (Palermo 1985) produces a conservative estimate at this site. This method uses laboratory settling column data to estimate the effluent suspended solids which are then combined with the results of the modified elutriate test to estimate contaminant loading.

### Harbor Monitoring

PCB levels detected at the monitoring stations within the harbor during the operational phases of the pilot study are compared with preoperational conditions in Table 5. The Coggeshall Street Bridge (station 2) was the focal point as the intent was to limit any increase in the movement of contaminants from the upper estuary to the lower harbor. The levels detected at station 2 did not represent a statistically significant increase above background conditions. These results indicate that the dredging and disposal operations conducted in the upper estuary did not significantly increase the movement of contaminants into the lower harbor.

TABLE 5. HARBOR MONITORING STATIONS\*

Phase**	Tide	Total PCB, $\mu\text{g/l}$							
		Station 1		Station 2		Station 4		Station 7	
		Average	Range	Average	Range	Average	Range	Average	Range
1	Ebb	1.7	0.4-3.8	0.6	0.4-0.8	0.12	0.05-0.22		
1	Flood	1.2	0.8-2.0	0.5	0.3-0.7	0.10	0.05-0.13		
2	Ebb	1.5	0.6-3.2	0.9	0.4-1.5	0.11	0.05-0.20		
2	Flood	1.1	0.6-2.4	0.4	0.2-0.7	0.08	0.07-0.09		
3	Ebb	1.4	0.8-2.0	0.7	0.4-0.9	0.11	0.10-0.12	0.9	0.87-0.94
4	Ebb	1.1	0.4-1.2	0.5	0.3-1.0	0.12	0.06-0.23	0.8	0.03-1.90
4	Flood			0.2	0.2-0.3	0.10	0.02-0.21		
5	Ebb	1.5	1.0-2.4	0.9	0.6-1.5	0.15	0.09-0.22	2.6	0.9-5.4
5	Flood			0.8	0.6-0.8	0.16	0.12-0.19		

\* Station 1 - Upstream of Pilot Study site.  
 Station 2 - Coggeshall Street Bridge.  
 Station 4 - Hurricane Barrier.  
 Station 7 - Adjacent to Pilot Study cove.

\*\* 1 - Preoperational.  
 2 - Dike Construction.  
 3 - Predredging.  
 4 - Dredging.  
 5 - CAD.

## CONCLUSION

The study obtained site-specific data on the operational characteristics of the dredges and the level of contaminant release and sediment resuspension associated with their operation. These data allowed for field verification of laboratory techniques for predicting contaminant release and have improved our ability to make estimates for future work in New Bedford. The study also addressed two major concerns regarding the evaluation of remedial actions for the upper estuary. It showed that dredges could successfully remove the contaminated sediment from the harbor. PCB levels in sediment remaining after two passes of the dredge were less than 10 ppm. It also showed that dredging and disposal operations could be carried out without a significant increase in the release of contaminants from the upper estuary to the lower harbor. This is evident from the results of monitoring at the Coggeshall Street Bridge (station 2) during the various stages of the study (Table 5).

The study, along with previous work performed during the EFS, has allowed the USACE to make specific recommendations to the EPA concerning future dredging work in New Bedford. EPA will rely on these recommendations in arriving at their decisions on remedial actions at this site.

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DEVELOPMENT OF THE HIGH-RATE DEWATERING SYSTEM  
OF BOTTOM SEDIMENTS AND WATER BLOOMS

AD-P006 455



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ABSTRACT

In the 10th, 12th, and 13th US/Japan Experts Meetings, it was reported that the synthetic purification system of lakes and ports using the continuous-vacuum precoat filter was most effective and economical to dewater and reuse bottom sediments and water blooms.

For several years, Japan has developed the high-rate, continuous-vacuum precoat filter which was more efficient and economical than the conventional apparatus.

The findings by the field investigations at Lake Kasumigaura and Otsuka Pond-Mito city, etc., are reported herein.

FUNDAMENTAL CONSIDERATIONS

Filtration Phenomena

Figure 1 shows the model of filtration phenomena prepared by Yoshino. Part (b) of Figure 1 illustrates the model of standard blocking filtration

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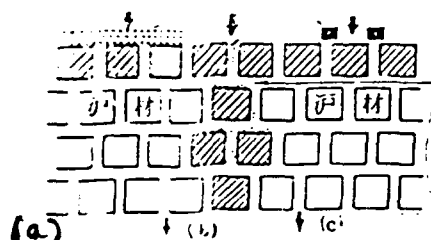


Figure 1. Model of filtration

with zinc particles in a dilute suspension deposit uniformly through flow-paths of a filter medium, such as deep filtration in the sand-filter or dewatering by a solar drying bed. Any continuous dewaterer is unsuitable to a suspension of this kind, owing to the heavy filter medium.

Meanwhile, in the case of cake filtration (Figure 1a) and complete blocking filtration (Figure 1c), in which suspended solids are seized at the surface of a filter medium, some continuous dewaterer may be available, because of the thin filter medium.

Figure 2 indicates the relation between batch filtration and continuous filtration (prepared by Yoshino). Figure 2 illustrates (a) a batch filtration process and (b) a continuous filtration process such as the Oliver filter. One of the controlling factors for the use of a continuous dewaterer is whether the wet cake formed on the filter medium can be discharged continuously.

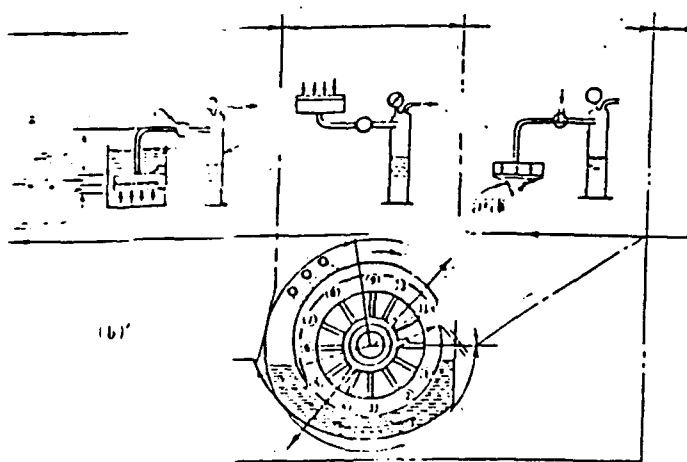


Figure 2. Relation between batch filtration and continuous filtration

Therefore, when suspended solids are very fine and tend to block a filter medium such as bottom sediments and water blooms, the conventional dewaterer, i.e., filter press and Oliver filter, cannot be applied, owing to difficulty of continuous cake discharge.

In this case, the continuous-vacuum precoat filter may be the most applicable, because of cleaning of the precoat-cake with an advancing knife by 50 to 100  $\mu\text{m}$  per rotation of drum, as shown in Figure 3.

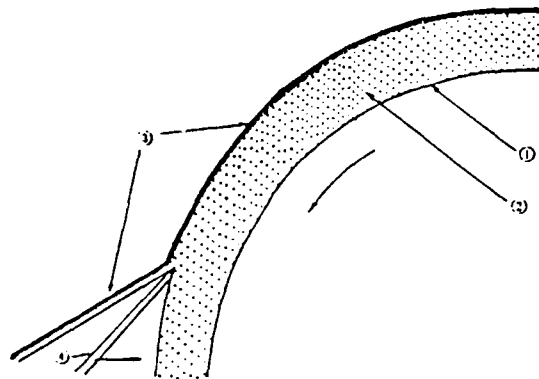


Figure 3. Continuous-vacuum precoat filter

### Filtration Characteristics

#### Cake Filtration

##### a. Batchwise filtration.

(1) The relation between filtrate volume  $V$  and dewatering time  $t$ , i.e., a filtration curve, may be expressed by a parabola, as shown in Figure 4, in accordance with the following equation:

$$t/V = (1/K)V + (2/K)V_m$$

where

$$K = 2A^2\Delta p g_c (1 - mw)/aw\mu\rho$$

$$\alpha = 2A^2\Delta p g(1 - mw)/Kw\mu\rho$$

$$= (1 - \epsilon)^3/\epsilon^3 (1/\rho_s)k(\phi/x)^2$$

$$V_m = AR_m (1 - mw)/\alpha w\rho$$

Then, the following relation can be derived:

$$V/t + V_m/t = [K(1/t) + (V_m/t)^2]^{1/2}$$

(2) Usually, the resistance of filter medium  $R_m$  is much smaller than the specific cake resistance  $\alpha$ . Therefore, the imaginary filtrate volume  $V_m$  corresponding to the

resistance  $R_m$  of the filter medium becomes negligible. In this case, the expression becomes, approximately:

$$V/t = 2A^2\Delta p g_c (1 - mw) / \alpha w \mu \rho \cdot t^{-1/2} = K \cdot t^{-1/2}$$

Then, as the filtration time  $t$  increases, the filtration rate  $V/t$  decreases in proportion to  $t^{-1/2}$ .

(3) The slopes of the dotted line in Figure 4 provide a comparison of the filtration rate of conventional dewatering methods; the continuous-vacuum drum precoat filter is seen to be the most effective dewatering technique from among the conventional processes.

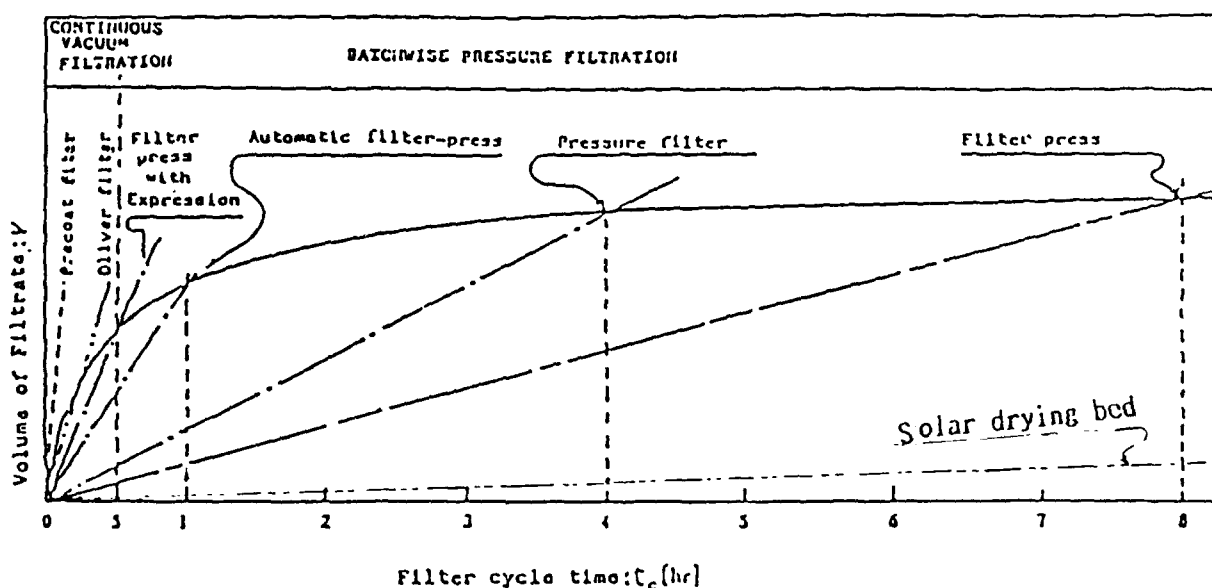


Figure 4. Filtration curve and dewatering apparatus

b. Continuous filtration. The relation between filtrate capacity  $V/A$  and cycle time  $t$  may be expressed with the following equation.

$$\begin{aligned} V_t/A_t &= k^{1/2} \cdot N^{1/2} \cdot \phi^{1/2} \\ &= k^{1/2} \cdot t^{-1/2} \cdot \phi^{1/2} \end{aligned}$$

#### Complete Blocking Filtration

The filtration characteristics may be expressed as shown in Figure 5, in accordance with the following equation:

$$\begin{aligned}
 dV/dt &= b (An' - m'V)/\mu \\
 &= bAn' - k_b V \\
 V &= (dV/dt)_0 / k_b (1 - e^{-k_b \cdot t})
 \end{aligned}$$

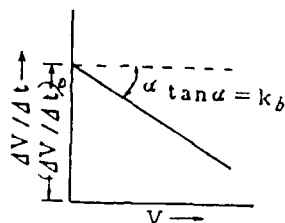


Figure 5. Complete blocking filtration

As the filtration time  $t$  increases, the filtration rate  $dV/dt$  rapidly decreases, as shown in Figure 5, because the filter medium may be blocked with fine particles such as bottom sediments and water blooms.

#### APPLICATION OF CONTINUOUS-VACUUM PRECOAT FILTER

Figure 6 indicates the scope of conventional solid-liquid separation apparatus (prepared by Yoshino).

The shaded portion in Figure 6 illustrates a wider range of application of the continuous precoat filter over the other dewaterer, i.e., filter press and super-decanter. In addition, the filtrate is clean, and the wet cake is low in moisture content.

#### DEVELOPMENT OF THE HIGH-RATE DEWATERING SYSTEM OF BOTTOM SEDIMENTS AND WATER BLOOMS

For a long time, the solid-liquid separation technique, especially on the precoat filtration, has been investigated as follows.

- a. Development of the compound filter aid. In order to remove nutrients such as  $\text{NH}_4\text{-N}$  and  $\text{PO}_4\text{-P}$  in a filtrate, the compound filter aid (mixed diatom earth with the powder of zeolite, crystbar, etc.) has been developed.
  - b. Development of the high-rate continuous-vacuum precoat filter. Studies on the continuous-vacuum precoat filtration have never been reported except in our papers.
- (1) Figures 7 and 8 show the bench-scale testing apparatus ( $0.24\text{-m}^2$ ) of continuous-vacuum precoat filter set up in our laboratory; Figures 9 and 10 show the pilot plant ( $2.0\text{-m}^2$ ) constructed on the site of Lake Kasumigaura.

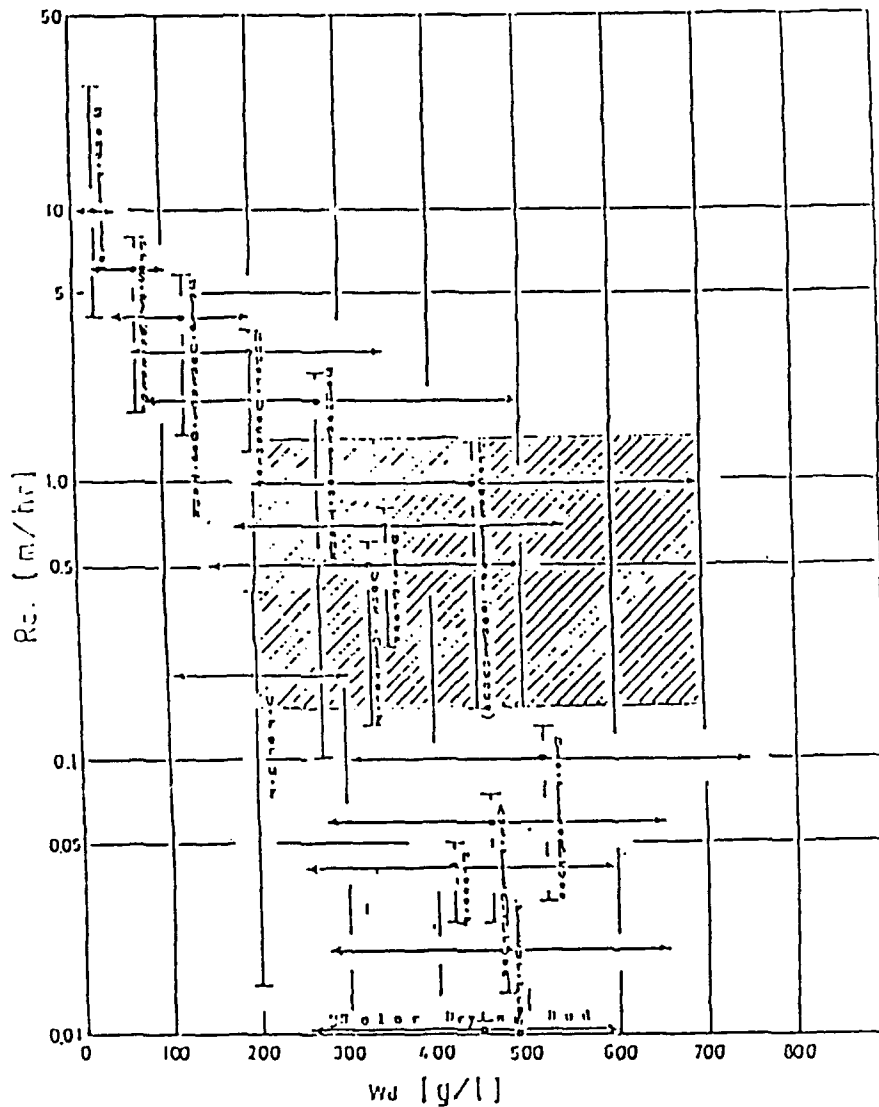


Figure 6. Solid-liquid separation process

- (2) Figure 11 shows the improved model in which two flanges are set up at the both sides of the filter drum, in order to prevent protrusion of precoat cake from the drum and to form a uniform cake. (Figure 12 shows the conventional type.)
- (3) Moreover, we have set up the swing agitator and constructed several perforated pipes through which the bottom sediments and water blooms enter into the bottom of a filter tank and uniformly upflow in the filter tank, as shown in Figures 13 and 14.
- (4) When the high-rate continuous-vacuum precoat filter in Figure 11 was compared with conventional type shown in Figure 12, the former was found to be superior. Figure 15 indicates that the high-rate type may be the best dewaterer available for the treatment of

bottom sediments and water blooms, from both a technical and an economic viewpoint.

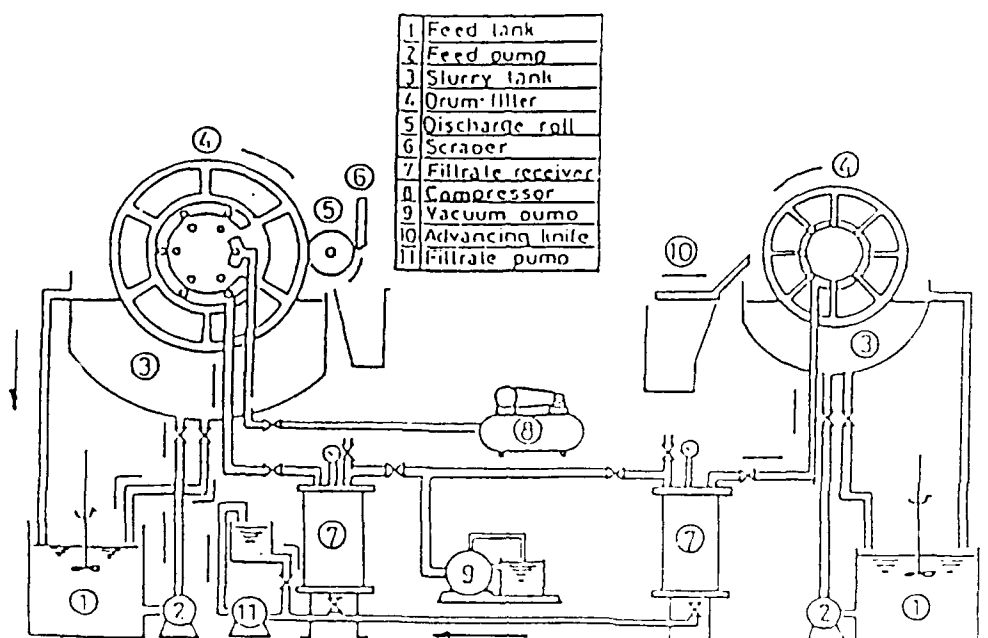


Figure 7. Experimental apparatus (continuous mode)

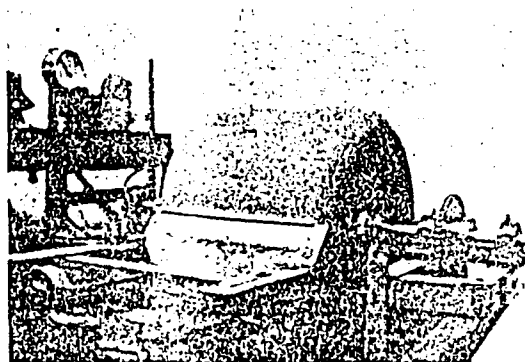


Figure 8. Bench-scale testing apparatus (0.24-m<sup>2</sup>)

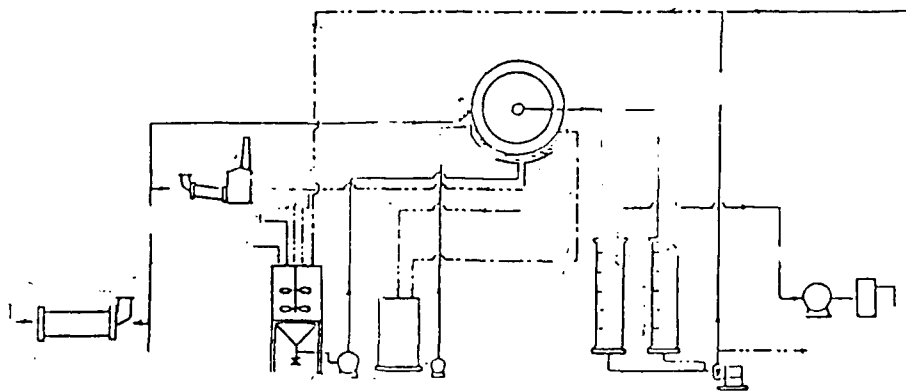


Figure 9. Sketch of the pilot plant (2.0-m<sup>2</sup>)



Figure 10. Pilot plant (2.0-m<sup>2</sup>)

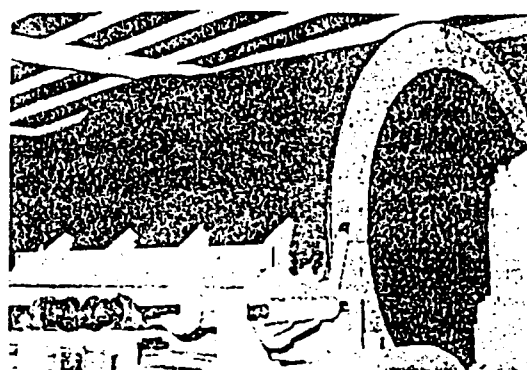


Figure 11. Improved model of the high-rate continuous-vacuum precoat filter (5-m<sup>2</sup>)

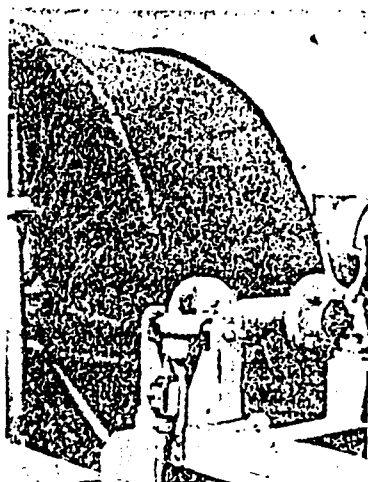


Figure 12. Conventional type filter (2-m<sup>2</sup>)

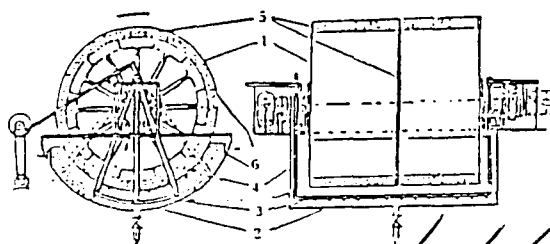


Figure 13. Sketch of the high-rate continuous-vacuum precoat filter

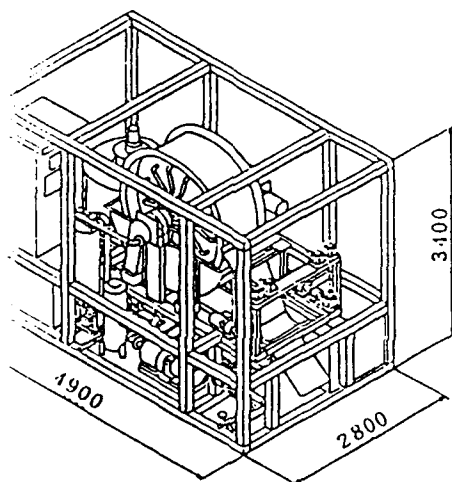


Figure 14. High-rate continuous-vacuum precoat filter

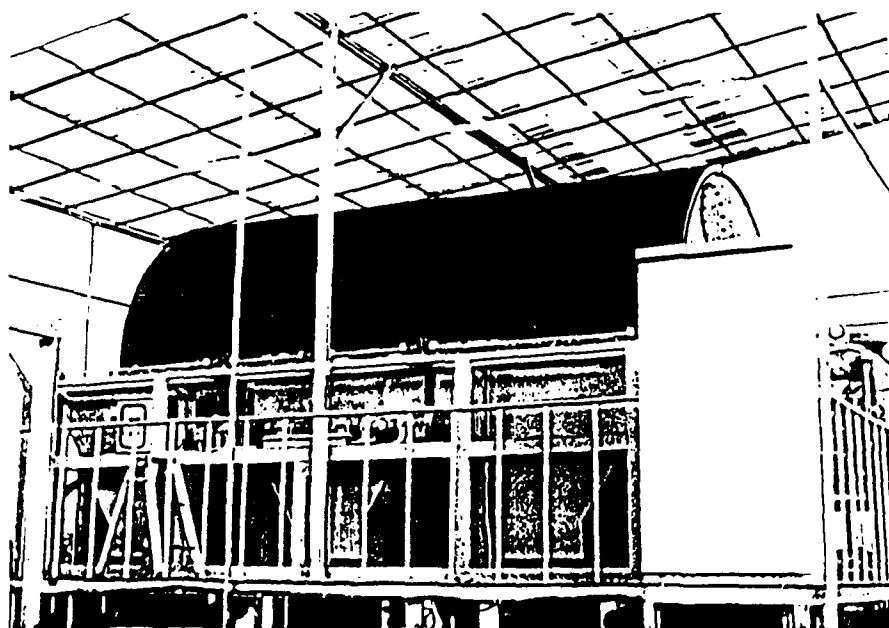


Figure 15. High-rate continuous vacuum  
precoat filter (47-m<sup>2</sup>)

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## EXAMPLE OF LATEST TECHNIQUES FOR BOTTOM SLUDGE DREDGING

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### ABSTRACT

Recently in Japan, the biggest problems of the bottom sludge dredging are lack of enough room for dumping areas and preventing water contamination during dredging in terms of environmental aspects. The new dredging system introduced at this time has been developed for the above purposes.

### INTRODUCTION

Recently, a bottom sludge dredging technique which permits a low level of turbidity and a small volume of land reclamation has been required as a part of muddy water purification works.

Sludge dredges today are mostly centrifugal-pump vessels with special suction heads. This type of vessel is used because solutions to environmental problems require dredging highly concentrated sludge in large quantities.

Extensive research and development into pump-type dredges with special suction heads have also been continued until the present. To suck up bottom sludge with a low water content, it is fluidized by stirring it to some extent. Then, some external water will begin to flow into the bottom sludge. Since those portions which are ready to flow are sucked up first, a decrease in the mean sludge content results.

In addition, expenses for disposing of the extra water produced in reclamation areas have been increasing in proportion to the sludge content.

On the other hand, there are backhoe-mounted vessels and grab dredges which are capable of dredging sludge with its natural water content unchanged. However, they are not very suitable for dredging bottom sludge intended to improve water quality in terms of environmental quality, because they involve water contamination, offensive odor, splashes of sludge, etc. Thus, bottom sludge dredging involves many difficulties, and comprehensive dredging techniques that take careful account of environmental pollution are strongly desired.

The bottom sludge dredging technique discussed here is a dredging system developed and applied to dredge bottom sludge in almost its natural state and discharge it to reclamation sites through pipelines. This paper presents the



principles and capabilities of bottom sludge dredging (high-concentration soft-sludge dredging) techniques, some achievements of dredging work, and the current situation of high-concentration soft-sludge dredging techniques.

## OUTLINE OF BOTTOM SLUDGE DREDGING SYSTEM

### Principles

The system here consists of a dredging (excavating and sludge collecting) section, a driving section for forcing the collected sludge forward, a discharging section for transferring sludge to the reclamation site, and an operating section for controlling all of the sections (Figure 1).

#### Dredging

A bucket wheel is used for dredging. Sludge is excavated up by allowing a dredging bucket wheel to run very slowly in a semicylindrical airtight submerged hood (Figure 2).

Bottom sludge is separated from surface water in the airtight hood (air atmosphere) and taken into a tank. This operation is so slow that it scarcely stirs the mud and thus permits dredging work to be performed with very little contamination to the surrounding water areas as compared with conventional dredging methods using cutter-equipped pump dredges and grab (or backhoe) type systems.

In addition, the bottom soil in bottom sludge removal work is not always soft ( $N \leq 2$ ) but is occasionally harder. Thus, the dredges have auxiliary excavators.

#### Discharge

Using this dredging system, bottom sludge is mostly dredged in a deposition state. Therefore, no conventional centrifugal pumps can be used for pipeline transfer in this case. Thus, an air pressure method is employed. Sludge is delivered into a discharge pipeline by a compression assisting unit. In the pipeline, the bottom sludge is mixed with compressed air fed continuously to give suitable plug and slug flows and is discharged to the reclamation site. There are few reports and documents published on the engineering details of the air-mixed compressed transfer method (for dredged sludge). Thus, at the present stage, data on proof tests and actual works are used as a guide.

#### Operation Control

The present system operates in the same way as conventional sludge dredges and cutter-equipped pump dredges. Basically, it is a swing-spat type. The operator can control dredging by observing on the monitor TV (Photo 1) how the bucket wheel in the airtight hood excavates sludge. The system is also provided with units for setting dredging locations, widths, etc.

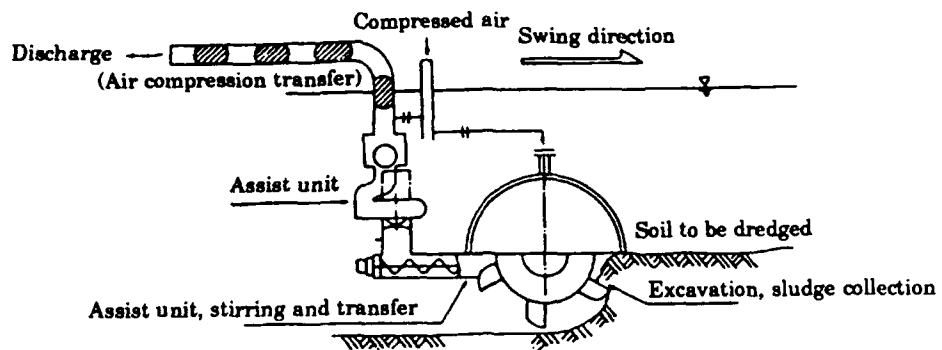


Figure 1. Sketch of bottom sludge dredging system

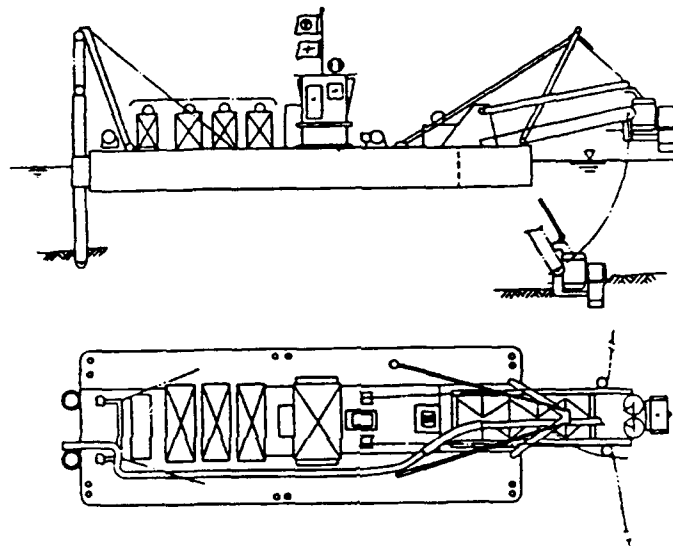


Figure 2. Vessel structure

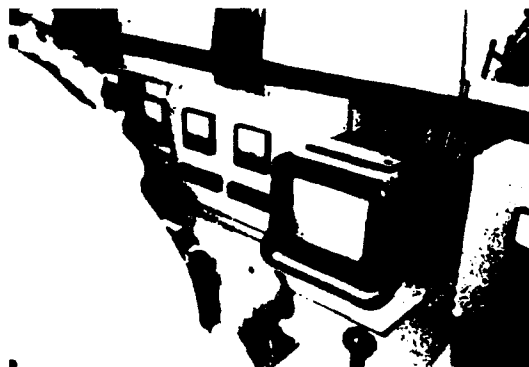


Photo 1. Television monitoring system

## Specifications of Bottom Sludge Dredge

Name.....	High-concentration soft-sludge dredger
Dredging and transfer system.	Bucket-wheel excavation, air-mixed compression transfer
Capacity.....	Soil, soft sludge
	Nominal capacity..... 100 m <sup>3</sup> /hr
	Discharge distance... 1,000 m (water content $\omega_o = 150\%$ )
	Dredging depth..... 10 m below the water surface
Vessel dimensions.....	29.5 m L $\times$ 8.5 m W $\times$ 1.8 m H, draft 0.9 m
Main engine.....	Air compressor 190PS (2-4 units)
Main generator.....	300 KVA (60 Hz)
Assist unit.....	75 kW
Pipe diameter.....	0.35 m
Total weight.....	200 t

## FEATURES OF BOTTOM SLUDGE DREDGER

### Sludge Dredged and Discharged in Near-Deposition State

The earth under the water is excavated by a bucket wheel running slowly in an airtight hood placed on the bottom so that soft sludge can be dredged almost as it is deposited.

### High-Concentration Sludge Transfer in Pipeline

Soft sludge is mixed with compressed air at a suitable ratio and is transferred in a pipeline (plug on slug flow), where the water content of the sludge is lower ( $\omega_o = 100$  percent) than in the case of a conventional centrifugal-pump system.

### Work Control

Dredging is done in an airtight hood. Consequently, it can be observed on a monitor TV, permitting accurate and delicate dredging control.

### Spread of Contamination Prevented

Dredging is done in an airtight hood, causing water contamination to be generated and spread much less than with dredging systems using cutter-equipped pump dredges or grabs.

### Less Excess Water

Because sludge is dredged almost as it is deposited and is discharged to the reclamation site, excess water generated and disposed of in the reclamation area is less than in a cutter-equipped pump dredger system, thus presenting no hazards of secondary pollution.

## CAPACITY

### Dredging Capacity

The present bottom sludge dredging system is entirely new. To present its dredging capacity, the results of proof tests and data obtained in actual construction works are used as guide. Since the capacity of the present system depends largely on the quality of soil and obstacles, it is essential when calculating dredging capacity to recognize the quality of the soil and the existing obstacles.

The present mechanical system was developed on the basis of dredging soft sludge (N value  $\leq 2$ ). The hardness of the soil and the water content in particular serve as basic measures of dredging capacity.

The properties (mean values) of the soil used for calculating capacity are as follows:

- |     |                            |   |
|-----|----------------------------|---|
| (1) | N value.....               | 0 ~ 7                                       |
| (2) | Weight of unit volume..... | $\gamma_t = 1.3-1.7 \text{ t/m}^3$          |
| (3) | Water content.....         | $\omega_o = 150-50 \text{ percent}$         |
| (4) | Quality.....               | silt (locally with fine sand<br>40 percent) |

Figure 3 illustrates the nominal capacities. Other parameters are as follows:

- (1) Discharge distance: 1,000 m, pipe gage: 0.35 m
- (2) Soil lifted represents measured values ( $\text{m}^3/\text{hr}$ ) based on N values.
- (3) Soil lifted represents soil deposited under the water.
- (4) For the soil lifting capacity, nominal capacity  $q_o = 100 \text{ m}^3/\text{hr}$  was used as a design point.
- (5) Air feed ( $\text{Nm}^3$ ) was  $76 \text{ m}^3/\text{min}$ .

Calculation of dredging capacity was based on the following expression:

$$Q = q_o \times E \times \eta \times T$$

where

- Q = work capacity (each dredged  $\text{m}^3/\text{hr}$ )  
q = nominal capacity (Figure 3)  
E = field work efficiency (Table 1)  
 $\eta$  = network time ratio (Table 2)  
T = operating time

### Discharge

Although the standard discharge distance here is 1,000 m, discharging is possible up to 2,000 m by increasing the air feed (decreasing soil ratio) though at lower discharge rates. Long-distance discharge is possible using an additional compressor on the pipeline. Where such compressors should be

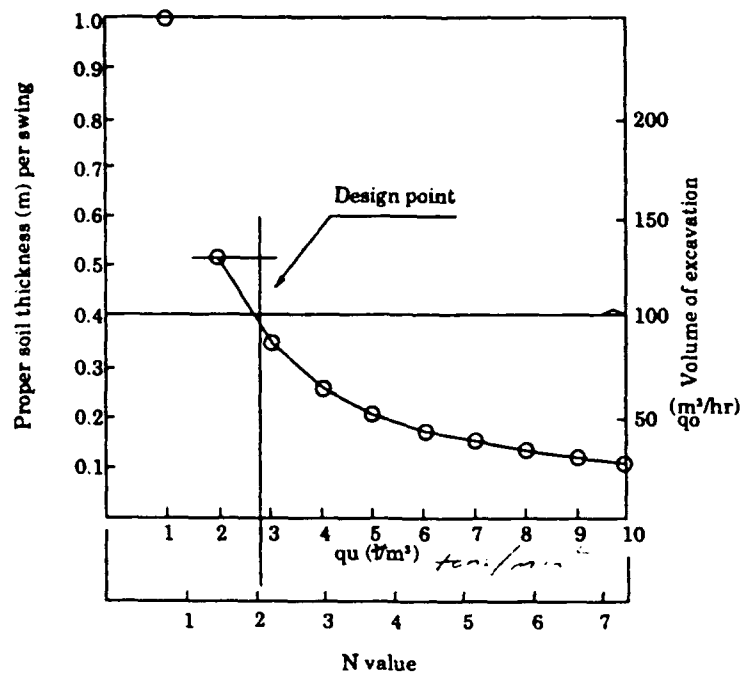


Figure 3. Nominal capacities

TABLE 1. EFFICIENCY OF FIELD WORK

Classification	Weather Tide Wave River flow	Soil thickness, horizontal shape, location, cross-section shape etc.		
		Right	A little smaller A little scattered A little changed	Small Scattered Changed
Efficiency of field work (E)	High	1.2	1.0	0.8
	Medium	1.0	0.8	0.6
	Low	0.8	0.6	0.4

Note: First, application categories are determined in accordance with weather, tide, and other conditions and then efficiency levels are determined by taking all dredging conditions into account.

TABLE 2. NETWORK TIME RATIOS

Classification	Soil thickness, horizontal shape, location, cross-section shape etc.		
	Right	A little smaller A little scattered A little changed	Small Scattered Changed
Net work time ratio ( $\eta$ )	0.95	0.90	0.85

TABLE 3. JUDGMENT OF MAIN PRESSURE

Specification of pump vessel		Right	A little smaller A little scattered A little changed	Small Scattered Changed
Electric	Diesel			
E100 - 250	Micropump	0.9m or up	0.9 - 0.4m	0.4m or less
	D100 - 350	1.2m or up	1.2 - 0.6m	0.6m or less
E250 - 500	D350 - 600	1.5m or up	1.5 - 0.8m	0.8m or less
E500 - 750	D600 - 800	1.8m or up	1.8 - 1.0m	1.0m or less
E750 - 1000	D800 - 1350	2.0m or up	2.0 - 1.2m	1.2m or less

located depends on soil quality, discharge distance, pipe gage, air rates, pressure, etc., and a comprehensive study including economy is necessary. In addition, under an air-compressor transfer system, with a content soil discharge rate, the discharge distance is correlated with the air rate (the supplied air volume) and is also related to the air pressure. For long discharge distances, suitable air rates are necessary. This relation can be represented by the "mix ratio."

$$\text{Mix ratio } R = \frac{\text{Soil lifted (kg/min)}}{\text{Air rate (kg/min)}}$$

With mix ratios obtained beforehand for sludge discharge distances (500, 1,000, 1,500, and 2,000 m) on the basis of the discharge pipe diameter, discharge capacities and air rates can be estimated to some extent.

Figure 4 shows the pressure gradient in a discharge pipeline. Under an air-compression transfer system, there is a stable pressure drop gradient subsequent to a rapid pressure drop caused before the first plug flow is generated. The pressure drop in the pipeline per 100 m is about 0.1 to 0.3 kg/cm<sup>2</sup>.

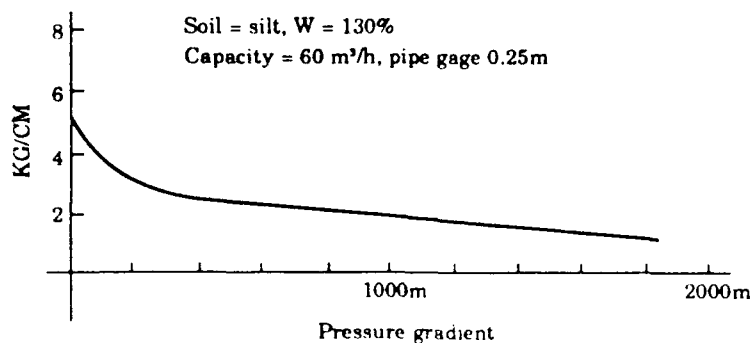


Figure 4. Pressure gradient

Plug and slug flows in the pipeline are generated and crushed repeatedly. Thus, it is difficult to obtain the flow rate in the pipeline accurately. If sludge is discharged efficiently, the quotient of the soil lifted ( $\text{m}^3/\text{hr}$ ) divided by the cross section of the pipeline ( $\text{m}^2$ ) is generally 0.5 m/sec (flow rate in pipeline meters per second).

### Volume Change

When bottom sludge is dredged and discharged, some water is included in it. In addition, if its water content is low ( $\omega_o = 100$  percent), some water must be added to it to raise the discharge efficiency. Thus, a certain quantity of bottom sludge dredged increases its volume a little before it is brought to the reclamation site. The volume change ratio is represented as follows:

$$V_R = \frac{1 + G_s \times W}{1 + G_s \times W_o}$$

where

$G_s$  = true specific gravity

$W$  = water content of sludge at reclamation site

$W_o$  = water content of bottom sludge

Figure 5 presents a chart for use as a guide to volume change ratios.

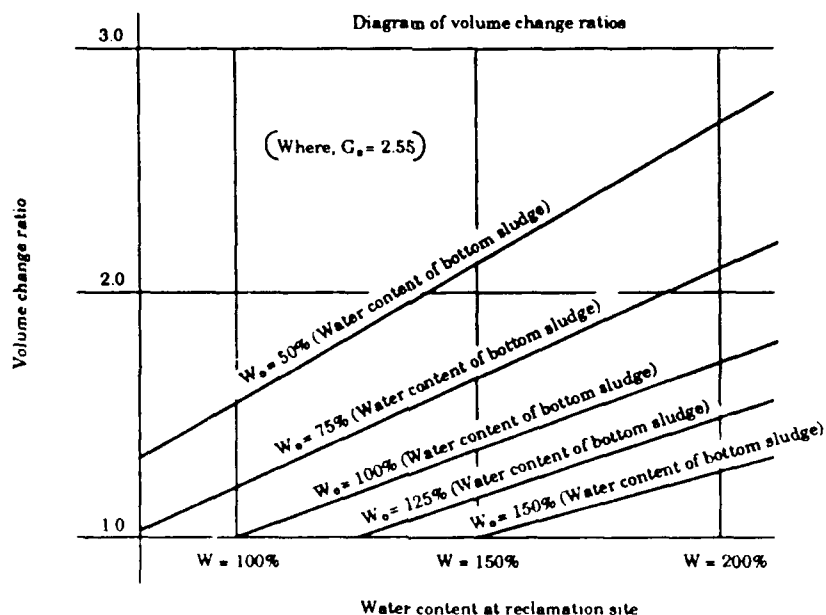


Figure 5. Diagram of volume change ratios

## Obstacles

Obstacles (pieces of rock, wood, vinyl, and fish nets) within the dredged material have a great effect on dredging capacity. An important problem is how to remove these from the bottom sludge. The present system incorporates a vibrating screen (7.0- by 5.0-cm mesh) to remove such obstacles.

Such screens cannot deal with large fragments, wire ropes, fish nets, etc. Thus, it is necessary to use an auxiliary means such as preliminary cleaning of the work area prior to dredging.

In addition, a selection can be made between returning the obstacles caught by the vibrating screen to the water bottom and disposing of them on land.

## Disposal of Excess Water

The water content of the bottom sludge discharged to the reclamation site under the present system is  $w_o = 100$  percent or above, and the sludge is very fluid because it is stirred well.

As the reclamation progresses, the stacked sludge sinks due to gravity, causing water in it to come up to the surface of the sludge. This pore water has been grain filtered, its suspended solids concentration being about 20 ppm. Besides, there are remaining water and rainwater in the reclamation area. A small-scale water treatment plant is provided to dispose of all of the excess water.

The calculated quantities of excess water generated by the conventional system using a cutter-equipped pump dredge and the present system using a high-concentration soft-sludge dredge are shown in Table 4. In the calculation, the volumes of sludge water lifted were obtained on the basis of the standard sludge contents for both dredges with a dredging rate of 100 m<sup>3</sup>/hr, and the volumes of excess water generated in the reclamation area were compared.

TABLE 4. VOLUMES OF EXCESS WATER GENERATED USING TWO TYPES OF DREDGES

Type of Dredge	Volume of Soil Lifted (m <sup>3</sup> /hr)	Dredging Rate (%)	Volume of Sludge Water (m <sup>3</sup> /hr)	Volume of Excess Water (m <sup>3</sup> /hr)
High-concentration soft-sludge dredger	100	10	125	25
Cutter-equipped pump dredger	100	80	1,000	900

## Achievements of Dredging Work

Between August 1987 and September 1989, the present system dredged and discharged about 560,000 m<sup>3</sup> of sludge.

An example of soft-sludge dredging was carried out in Akita Prefecture between August 1987 and February 1988. The two vessels used were high-concentration soft-sludge dredges each with a nominal capacity of 110 m<sup>3</sup>/hr. Figure 6 is a flowchart of the work.

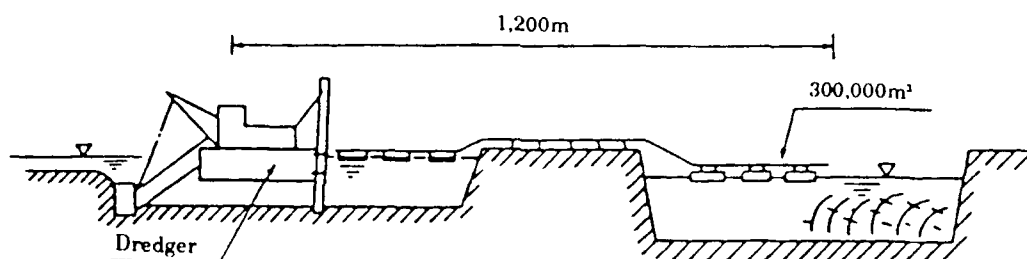


Figure 6. Flowchart of dredging work

## Soil Data

Table 5 lists the soil data.

TABLE 5. SOIL DATA

Sample No. (Depth)		No. RED (m ~ m)		No. WHITE (m ~ m)	
Grains 4.76 mm or greater	%	0		0	
Granule (4.76 - 2 mm)	%	0	0	0	0
Coarse sand (2 - 0.42 mm)	%	0		0	
Fine sand (0.42 - 0.074 mm)	%	8	8	8	8
Silt (0.074 - 0.005 mm)	%	8		8	
Clay (0.005 mm or less)	%	58		55	
Colloid (0.001 mm or less)	%	(20)		(17)	
Filtrate through 2,000-μm screen, wt	%	100		100	
Filtrate through 420-μm screen, wt	%	100		100	
Filtrate through 74-μm screen, wt	%	92		92	
Max. grain diam., mm		0.25		0.42	
60% grain diam., mm		0.021		0.016	
30% grain diam., mm		0.0042		0.0030	
10% grain diam., mm		--		--	
Uniformity coefficient, U <sub>c</sub>		--		--	
Curvature coefficient, U <sub>c'</sub>		--		--	
Soil grain specific gravity, G <sub>s</sub>		2.569		2.583	
Dispersant					

## Records of Dredging

Table 6 gives the achievements of dredging in each zone.

TABLE 6. ACHIEVEMENTS OF DREDGING

<u>Dredging Zone</u>	<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>	<u>Total</u>
Soil excavated (m <sup>3</sup> )	79,300	125,600	103,000	307,900
Operating time (hr-min)	930-15	1,123-55	936-36	2,990-46
Excavating capacity (m <sup>3</sup> /hr)	85.2	111.8	110.0	103.0

## Soil Volume Change Ratio

Sludge was sampled from the bottom deposit and at the discharge port at the reclamation site while the dredgers were operating. The weights of the sludge in the measuring cylinders and the apparent weights of unit volumes were measured, and the differences in value between the bottom deposit and the discharge port were converted into earth volume change ratios. Table 7 shows the actual values of the volume change ratio that were achieved.

TABLE 7. SOIL VOLUME CHANGE RATIOS

<u>Dredging Zone</u>	<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>	<u>Total</u>
Soil volume change ratio	1.349	1.253	1.225	1.269

## Spill-Water Treatment

The spill water generated by dredging was grain filtered due to self-weight consolidation. Thus, there was no need to use chemicals when disposing of it. To treat with the remaining water and rainwater in the reclamation area, a spill-water treatment plant was prepared, but it was not needed.

## CONCLUSION

The bottom sludge dredging system described is an example of a technique that was established for dredging sludge as it is deposited and discharging it to a land reclamation site, which has been conventionally considered to be difficult.

It is believed that this technique will be useful for reducing the total cost of dredging and land reclamation works while preserving the environment

by preventing water contamination, reducing the sizes of disposal areas, improving soil, and reducing the cost of disposing of the spill water, all of which are required in dredging and land-reclaiming works today.

AN UPDATE OF DREDGED MATERIAL CAPPING EXPERIENCES IN THE UNITED STATES

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**AD-P006 457**



ABSTRACT

There has been considerable experience in the United States regarding level-bottom capping operations in the New England area and in New York Bight. These operations involve placement of contaminated sediments at open-water sites by bottom dumping from hopper dredges or barges, forming a mound on the bottom followed by placement of a cap of clean sediment. More recent US capping experiences involve hydraulic placement of highly contaminated sediments from a Superfund project in New Bedford, Massachusetts, in preexcavated subaqueous pits. These sediments were capped by hydraulically placing clean sediment using a submerged diffuser. Other recent innovations include controlled placement of materials in thin layers by pipeline and from barges, recently accomplished in Puget Sound. Results from these projects and planned demonstrations of other capping procedures will extend capping experience in the United States to a wide range of project conditions.

INTRODUCTION

When dredged material is placed in open-water sites, there is potential for both water column and benthic effects. The release of contaminants into the water column is not generally viewed as a significant problem for dredged material from most navigation projects. The acceptability of a given material for unrestricted open-water disposal is therefore mostly dependent on an evaluation of the potential benthic effects. Capping is considered an appropriate contaminant control measure for benthic effects in the US Army Corps of Engineers (Corps) dredging regulations and supporting technical guidelines and is recognized by the London Dumping Convention as a management technique to "rapidly render harmless" otherwise unsuitable materials.

Capping is the controlled accurate placement of contaminated material at an open-water disposal site, followed by a covering or cap of clean isolating material. For purposes of this paper, the term "contaminated" refers to material found to be unacceptable for unrestricted open-water disposal because of potential contaminant effects, while the term "clean" refers to material found to be acceptable for such disposal. Level-bottom capping may be defined as the placement of a contaminated material on the bottom in a mounded

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configuration and the subsequent covering of the mound with clean sediment. Contained aquatic disposal (CAD) is similar to level-bottom capping but with the additional provision of some form of lateral confinement, usually an existing or constructed depression, to minimize spread of the materials on the bottom.

Level-bottom capping is a dredged material disposal alternative routinely used in the New England area and New York Bight area in the United States. Results of these efforts have been reported in previous US/Japan Experts Meetings (Semonian 1983, Mansky 1984). Level-bottom capping and/or CAD has also been successfully used for placement of highly contaminated sediments and has been demonstrated or evaluated as an alternative for a variety of disposal conditions (Truitt 1987a, 1987b; Environmental Laboratory 1987; Palermo 1989; Palermo et al. 1989).

Improved equipment and techniques for capping are being investigated as a part of the Corps' Dredging Research Program (DRP), managed by the US Army Engineer Waterways Experiment Station (WES). Case studies of actual capped disposal projects are useful in determining the effectiveness of the procedures used and for planning subsequent projects. Recent case studies completed in the United States include hydraulic placement of highly contaminated sediments from a Superfund cleanup project in New Bedford, Massachusetts, in preexcavated subaqueous pits and controlled placement of materials in thin layers by pipeline and from barges, recently accomplished in Puget Sound. In addition, case studies planned for the near future involve controlled placement of material by a bottom-dump barge at a deepwater site in the New England area and controlled placement of material from barges for an in situ capping operation in Puget Sound. The results from these efforts will be used as case studies in the DRP for developing guidelines for capping under a wider variety of operational conditions. Descriptions of both the completed and planned projects are given in this paper and provide an update of US capping experiences.

#### NEW BEDFORD CONTAINED AQUATIC DISPOSAL EVALUATION

The upper estuary of the Acushnet River at New Bedford, Massachusetts, is highly contaminated by PCBs discharged by industries in the years prior to the 1980's. PCB concentrations in the sediments range from a few parts per million (ppm) to over 100,000 ppm. The area was designated a Superfund cleanup site by the US Environmental Protection Agency (EPA) in 1982.

Conceptual designs of dredging and disposal alternatives were developed and evaluated for their implementability and potential for contaminant release (Francingues and Averett 1988, Averett et al. 1989). The alternatives were field tested during a pilot field-scale test from May 1988 to February 1989 (US Army Engineer Division, New England 1989). One of the five alternatives investigated included a demonstration of CAD. This demonstration involved dredging 1,680 cu m of contaminated material from the estuary, followed by 2,980 cu m of cleaner cap material, and placing it in a confined disposal facility (CDF) on shore. As a result, a CAD cell was created in the bottom of the estuary where an additional 535 cu m of contaminated material was dredged from a second area and subsequently capped with an approximate 0.7-m thickness of clean material. A layout of the dredging areas, the CDF, and the CAD cell is shown as Figure 1.

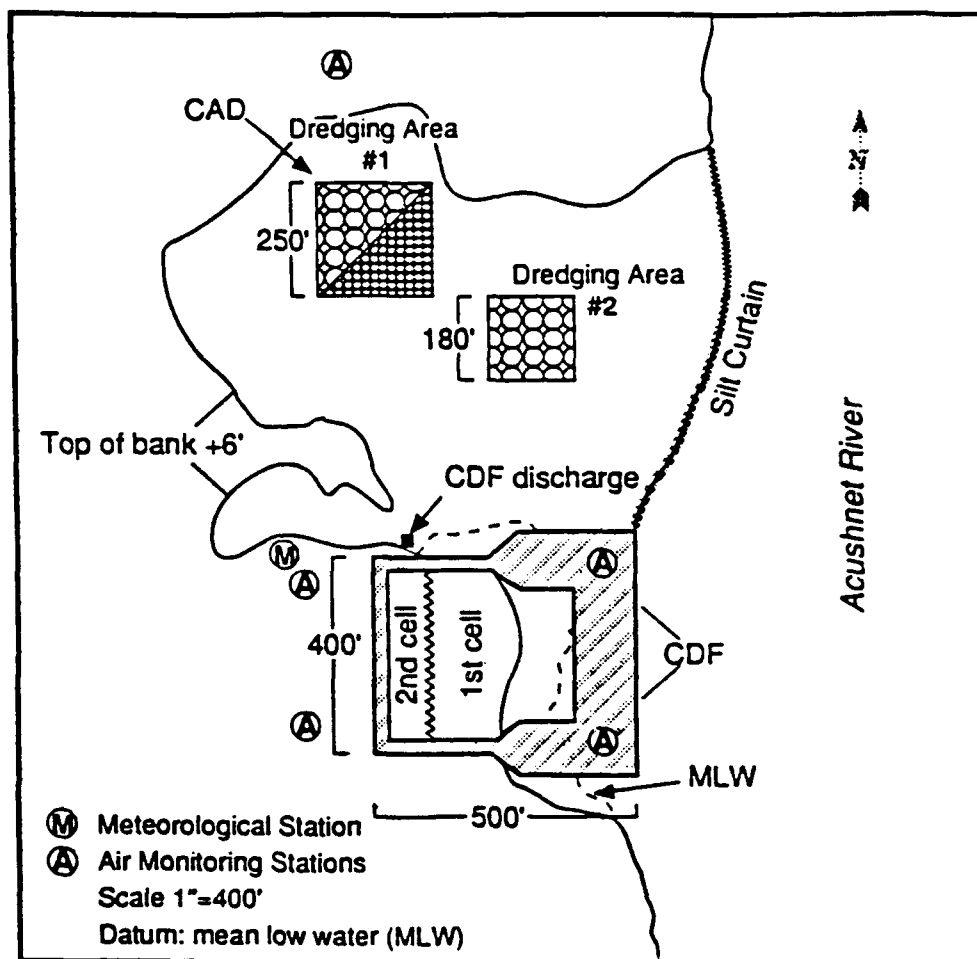


Figure 1. Layout of dredging and disposal areas for the New Bedford, Massachusetts, Superfund Pilot Project

A major consideration for this project was the potential for contaminant release to the water column during dredging and placement of contaminated material in the CAD cell. The dredging was accomplished using small hydraulic pipeline dredges equipped with cutterhead, matchbox, and horizontal auger dredge heads. Placement of both contaminated material and capping material within the CAD cell was accomplished using a submerged diffuser to minimize resuspension of material. Water quality in the vicinity of the dredging operation and the CAD cell was extensively monitored during the demonstration. Both suspended solids and PCB concentrations were elevated above background levels near the upper estuary. Sediment samples through the cap will be taken to monitor the integrity of the completed cap and to detect any migration of contaminants into the cap.

## CAPPING PROJECTS IN THE PUGET SOUND AREA

### Lower Duwamish

#### Waterway CAD Demonstration

The Seattle District of the Corps conducted a demonstration of CAD in the Lower Duwamish River near the city of Seattle, Washington, in 1984 (Truitt 1986). This demonstration involved placement of 840 cu m of contaminated material in an existing depression using a conventional bottom-dump barge. Three barge loads of clean sand were used to cap the deposit. The release of capping material from the barges was accomplished by gradually opening the barge to allow a slower release of the sand, which ensured a more even cap deposit and avoided displacement of the contaminated material. Electronic positioning was used for control of the barge locations during the operation. A cross section of the completed CAD cell is shown in Figure 2.

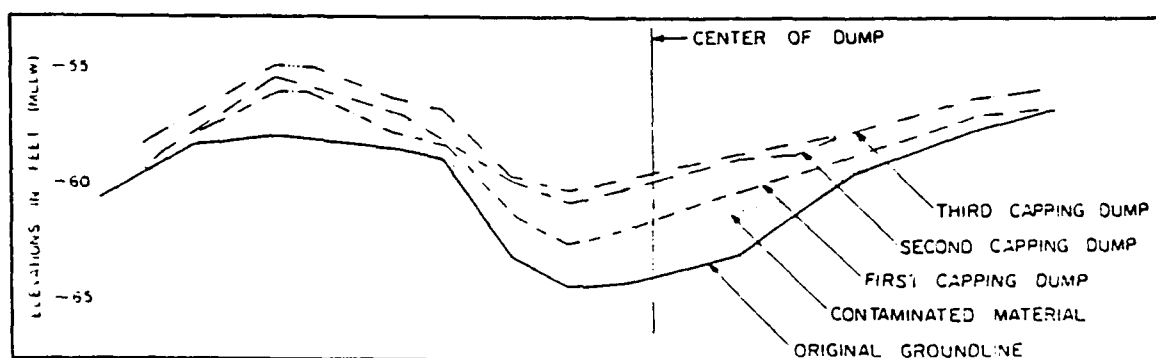


Figure 2. Cross section of the Duwamish River CAD demonstration project

The placement operation was monitored for the potential release of material into the water column. Also, the deposit of contaminated material and capping material was surveyed to determine the thicknesses as placed. Cores were taken through the cap immediately after replacement, as well as after 6, 12, and 18 months. The monitoring indicated that between 4 and 8 percent of the material was released during placement. No movement of contaminants into the cap was apparent after 18 months. Additional core samples were recently taken at 5 years following completion of the cap, and preliminary results from these cores also indicate no movement of contaminants into the cap.

#### One Tree Island Marina CAD project

A second CAD project was completed in the Puget Sound area in 1987 (Sumeri 1989). This project involved excavation of 2,980 cu m of contaminated material by a conventional clamshell dredge. This material was held in three barges. Then, 7,190 cu m of clean material was excavated by clamshell and placed at another disposal site, creating a conical pit. The contaminated material was then dumped into the pit. Clean material was placed directly from adjacent areas to cap the pit with a 1.2-m thickness. Monitoring will be accomplished to verify the integrity of the cap. A cross section of the project is shown in Figure 3.

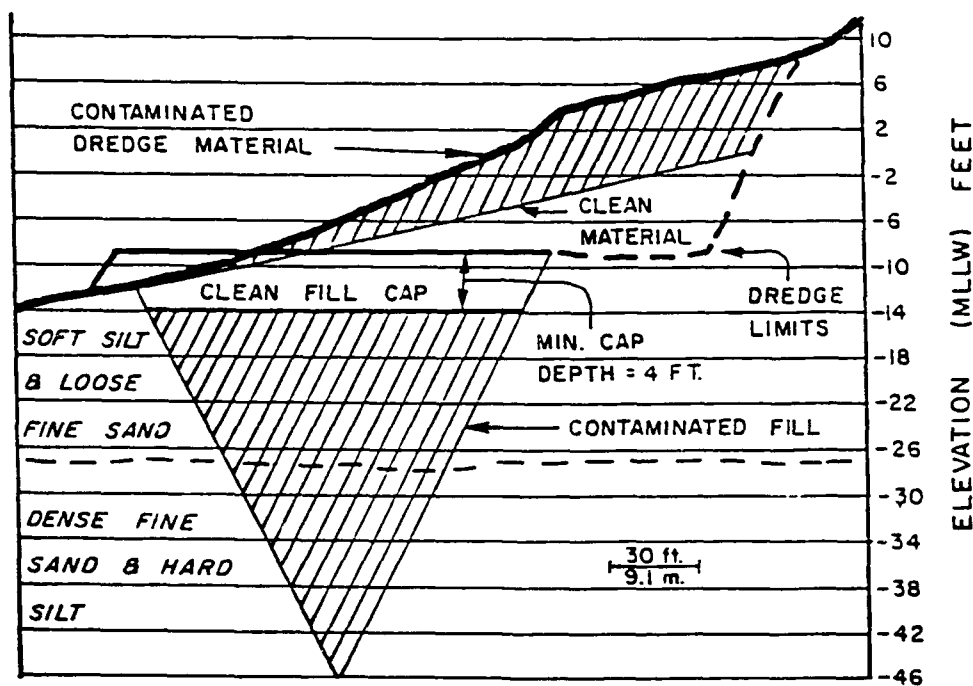


Figure 3. Cross section of the One Tree Island Marina CAD project

#### Simpson Tacoma Kraft In Situ Capping Project

The Tacoma, Washington, Harbor and its adjacent Waterways and nearshore areas are Superfund cleanup sites. The nearshore area sediments at the Simpson Tacoma Kraft company were contaminated with a variety of organic chemicals. The company performed remedial work to clean up the sediments and provide source control and restore natural habitat in 1987 (Sumeri 1989). The remedial work consisted of raising the existing bottom from subtidal to intertidal elevations by capping the contaminated materials in situ. Approximately 153,000 cu m of clean sand was placed as a cap using conventional cutterhead pipeline dredges. A diffuser box with a spud barge provided for more even distribution and control of the sand during placement. The cover was placed in a thin lift by swinging the diffuser box through a wide arc, then advancing the spud barge. Long-term monitoring of the cap will be accomplished to ensure its effectiveness. A typical section of the completed cap is shown in Figure 4.

#### MASSACHUSETTS BAY DISPOSAL SITE CASE STUDY

The New England Division (NED) of the Corps will conduct a demonstration of controlled placement techniques at the Massachusetts Bay Disposal Site (MBDS), formerly the Foul Area Disposal Site, located approximately 22 nautical miles east-northeast of Boston, Massachusetts, in a water depth of 90 m (Figure 5). Dredging will be conducted using standard clamshell equipment with placement from bottom-dump barges. The objective is to demonstrate that a tight disposal mound suitable for capping can be formed on the bottom at this water depth by carefully controlling the disposal operation. All

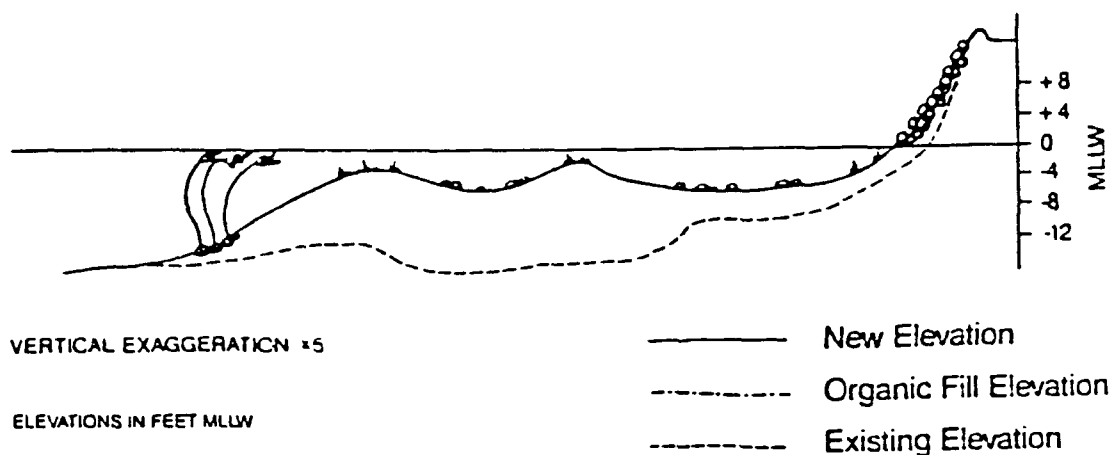


Figure 4. Cross section of the Simpson Tacoma Kraft capping project

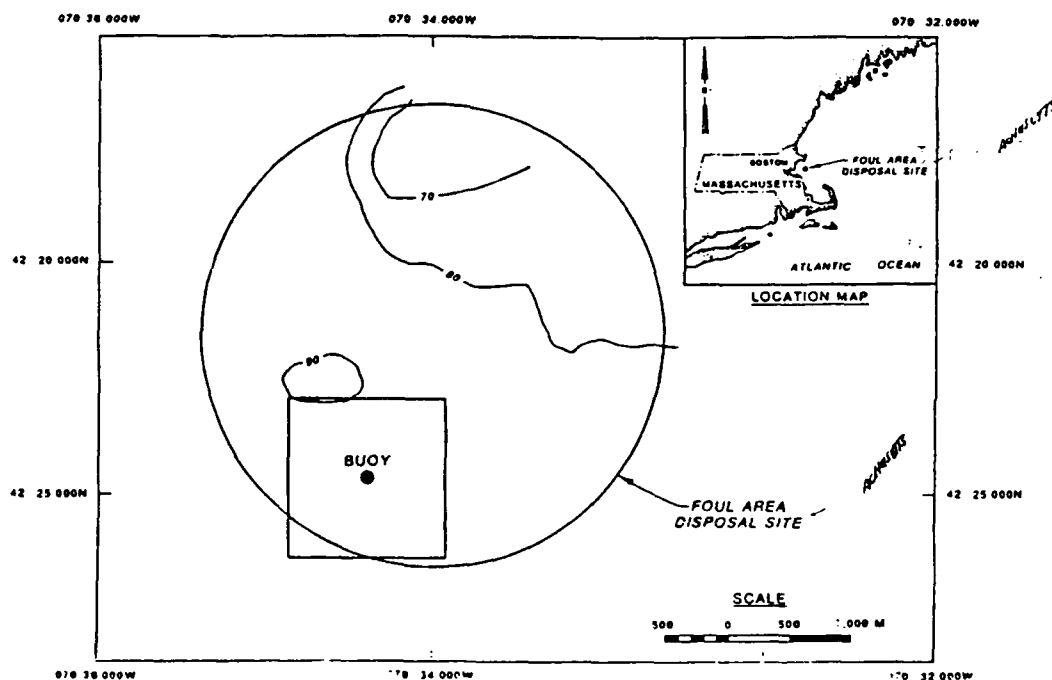


Figure 5. Location and plan for the Massachusetts Bay Disposal Site capping demonstration project

releases of material from the disposal barges will be within 10 m of a taut-line buoy. A successful demonstration will support the technical feasibility of capping in deepwater locations. The monitoring for the demonstration will be conducted as a part of NED's Disposal Area Monitoring System (DAMOS) program (Fredette et al. 1987).

The need to address the question of capping feasibility at the MBDS has become more urgent because of current project needs and projections that there will be large volumes of relatively contaminated sediments dredged in the Boston region in the next several years. The alternative of open-water disposal followed by capping needs to receive serious consideration as it may

prove to be economically compelling. Consequently, there is a need to provide a sounder technical basis on which to judge the technique than that which currently exists.

The need for such a demonstration stems from the controversy over proposed capping operations in deep water. Placement of dredged material without excessive dispersion and spread, formation of mounds which can be successfully capped, and prediction and monitoring of such behavior are critical issues for deepwater capping projects which need further investigation (Palermo 1989). Operational capability must be proven, and predictive capability must be verified for deepwater conditions. The principal concern of capping at deepwater sites is the impression that large volumes of capping sediment may be needed to effectively cap relatively small volumes of contaminated sediment.

The MBDS demonstration will be conducted with approximately 45,000 cu m of sediment suitable for open-water disposal, so no actual cap of cleaner material will be necessary. This volume was chosen as representative of the volume expected in future projects. Sediment grain size will also be considered so that it will be representative of future projects. A predisposal bathymetric survey around the location of the taut-wire buoy and baseline sediment profiling camera data have also been collected. Additional bathymetry and sediment profiling camera data will be collected at intervals during and following disposal operations for comparison.

The inspectors and tug operations will be thoroughly briefed regarding the objectives of the study prior to beginning operations. During the disposal operation, all releases of dredged material will be controlled to within 10 m of the buoy. If weather conditions do not permit such control, the barges will be diverted to a far removed alternative buoy until weather conditions again permit the required control. This precaution will ensure that all material placed at the study site will be released within the 10-m radius throughout the study. Electronic positioning equipment will be used to determine the location of the disposal vessel.

The study will determine the areal extent and thickness of the dredged material deposit formed at the MBDS as a result of the controlled placement. It is expected that with a 10-m radius of release at the surface, a disposal mound with a radius of approximately 250 m will be created. The ability to create a mounded deposit for this project will greatly increase confidence in the ability to successfully execute capping projects at the MBDS site.

#### DENNY WAY DEMONSTRATION

The Seattle District of the Corps and the Municipality of Metropolitan (METRO) Seattle, Washington, are cooperating in a demonstration capping project for contaminated sediments adjacent to the Denny Way Combined Sewer Overflow (CSO) (Sumeri 1989). A combined sewer overflow is one that discharges both untreated sanitary sewage and stormwater runoff, acting as a relief point during peak storm events so as not to overload the sewage treatment facility. The CSO at Denny Way is the largest in the area and has about 50 overflow events a year. Historical discharges of metals and polynuclear aromatic hydrocarbons (PAH's) into the sewer system have resulted in sediment contamination in the immediate vicinity of the discharge point. A recently

developed CSO control plan and source control activities will greatly reduce future contaminant loadings.

The Denny Way demonstration will involve placement of a sand cap over the contaminated sediments as shown in Figure 6. A unique method of controlled placement is proposed to place the desired thickness of cap over the contaminated area. The sand capping material will be taken from a Corps maintenance dredging project. Conventional clamshell equipment will be used to dredge the material and place it in bottom-dump barges. The cap will be placed at the Denny Way site by pushing the barge sideways while sprinkling a 39-m-wide blanket of sand over the bottom. The sprinkling action will be accomplished by controlling the rate at which the split-hull mechanism of the disposal barge is opened. Two radio tide gages with pressure transducers located in stilling wells at each end of the disposal barge will be used to measure barge displacement, which is subsequently used to determine the sand sprinkling rate. A shore-based laser positioning system will track the barge. The barge position and displacement data are to be telemetered to the attending tug. The onboard monitor screen will show the intended barge course, actual barge position, and the sand sprinkling rate. In this way, the speed of the barge and thus the rate of application of sand can be adjusted as the barge is moved across the area to be capped. A 0.9-m cap is planned. METRO will conduct future testing of the cap effectiveness. The study will demonstrate the feasibility of using this approach and will provide information on material placement rates, operational logistics and problems, and cap coverage obtained for the project.

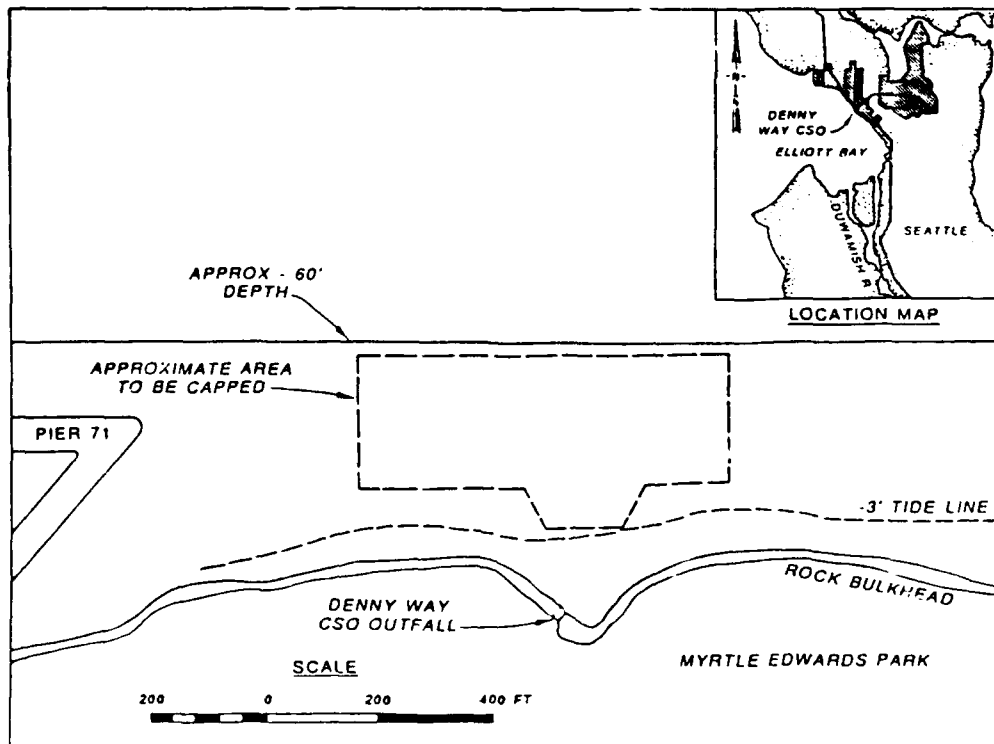


Figure 6. Plan for the Denny Way capping demonstration project

## SUMMARY

A sufficient number of capping projects have been completed in the United States under a range of conditions to establish that the concept is technically and operationally feasible. The information gained in the recently completed projects and planned projects described above will be used in developing Corps guidelines for capping under a wide variety of conditions.

## ACKNOWLEDGMENT

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TREATMENT OF DREDGED SLUDGE BY MECHANICAL  
DEHYDRATION

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ABSTRACT

Sludge deposits in the water area damage the ecosystems and environments; their elimination has always been an urgent task for human communities. Generally, sludge deposits are dredged out of the bottom of the water area, transported to, and discharged at a large disposal area on land. Recently, however, it has become increasingly difficult to secure disposal areas and routes of speedy transportation for disposal of dredged sludge. Accordingly, there is an urgent need to reduce both the volume of dredged sludge and the size of the disposal area.

This mechanical method is different from the conventional engineering dehydration by loading, consolidation, and drainage in that the dredged sludge is separated into sludge cakes and clean water that can be returned to the water area through mechanical centrifugal dehydration. Sludge deposits are distributed thin and wide on the bottom of the water area, and a pump dredge has been proved effective in many cases for dredging the upper layers of sludge deposits accurately and without creating turbidity in water. This mechanical sludge treatment technique can be most efficient when used in combination with a pump dredge.

This method offers the following advantages:

- a. It requires smaller space for treatment and disposal of dredged sludge than the conventional method.
- b. Facilities and costs for transportation can be reduced.
- c. Various systems can be adopted for transportation of sludge cakes.
- d. This system is transportable and compact and can be constructed anywhere either on land or on water.

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## INTRODUCTION

The closed water area such as a lake, pond, river, or moat is liable to accumulation of sludge due to the load of wastewater flowing in from the plants and residences in its surrounding area. Such sludge deposits pollute water and environments, and projects are going on or under planning throughout Japan for elimination of accumulated sludge.

Generally speaking, sludge is removed from the bottom of the river or other bodies of water by dredging and transferred to the disposal area on land. However, since it has become increasingly difficult to find an area for sludge disposal near the working site, a new system to carry out the sludge disposal with smaller space has been required. In this connection, a mechanical dehydration system has been considered as one of the effective solutions.

This system has been frequently used in disposing sludge originating from sewage, purification of water, wastewater from factories and mines, but its capability and applicability for disposal of accumulated sludge have not been fully ascertained yet.

To examine the applicability of the system for accumulated sludge disposal, a screw-decanter type centrifugal dehydrator was selected from among many types of dehydrators, under the judgement that the machine can not only save the working space but also treat a large quantity of sludge. During the process of experiment, peripheral units have been added to develop a plant system which can fully display centrifugal features of the machine.

This report introduces an outline of dredging techniques which form the basis for sludge treatment aimed at the improvement of water-area environments, as well as the features and samples of application of the mechanical dehydration treatment.

## SLUDGE TREATMENT AND DISPOSITION

### Characteristics of Sludge

Sludge deposits are classified into organic sludge, which contains a large volume of organic matters; poisonous sludge, which contains poisonous matters; and greasy sludge, which contains oil. Sludge deposits, which are the target of elimination efforts in many regions, are overwhelmingly organic.

Characteristics of organic sludge are assessed by ignition loss, COD (chemical oxygen demand), sulfide, nitrogen, phosphorus, and other index items, and the quantity of each item is very large. Other features include high water content which makes the sludge soft and fluid, small soil-particle specific gravity, and the main components of fine soil particles such as silt and clay. Table 1 shows the results of a study on characteristics of sludge deposits in various regions.

Distribution of sludge deposits, on the other hand, has different histories and features including thickness in different locations. There is a general tendency, however, that the upper layers contain more organic matters. Figure 1 indicates samples of sludge-deposit depth distribution.

TABLE 1. CHARACTERISTICS OF ORGANIC SLUDGE BY REGION

Region		1	2	3		4	5	6	7	8	9	10	11	12	13	14	15
Item		Togo Pond	Mutsu Ogawara	Ito River	Mayashida River	Niigata Bay	Tegayama	Mito Bay	Nirashima Castle	Mahanomai	Takamatsu Port	Nachikubo Port	Kasumigaoka	Tsu Matsuzaka	Koyama Pond	Otake Port	Old Shiba River
Mud color		Dark	Darkish gray	Dark	Gray	Darkish gray		Dark	Dark	Dark	Dark	Dark		No. 2, 4 dark gray		Dark	
Specific gravity		2.628	2.251	2.25	1.75	2.638	2.60	2.572	2.286	2.61	2.112	2.29	2.613	2.57	2.561	2.152	2.505
Basic characteristics	Particle size distribution	Gravel (more than 2,000 $\mu$ ) (%)							0	0	0	0	0	0	0	0	0
		Sand (2,000 - 74 $\mu$ ) (%)		7					42.4	5.0	4.0	12.6	12	3.5	5.0	25.4	28
		Silt (74 - 5 $\mu$ ) (%)		30					10.2	31.0	53.0	65.4	39	71.2	53.0	34.1	36
		Clay (less than 5 $\mu$ ) (%)		63					47.4	64.0	43.0	22.0	49	25.0	42.0	40.5	36
	Water content ratio (%)		594.4	387.8	151	1940	470.7	187.0	438.8	268.9	358	293	138.4	302.4	194.1	352	264.2
	Moisture density (g/cm <sup>3</sup> )		1.08 ~1.11	1.133	1.33	1.20	1.122		1.108	1.19	1.194	1.047	1.32	1.189	1.30	1.161	1.172
	Consistency	Liquid limit (%)		144.7	132.5	67.0	208.2	51.0	156	288.3	75.3	172.2	204.3		100.5	121.1	83.1
		Plastic limit (%)		73.7	80.5	35.1	121.8	40.4	50	132.7	51.0	44.0	35.9		25.9	43.6	36.9
	pH	Distilled water method		8.72 ~7.50	7.3	8.1	7.8	8.82		7.80	7.6	7.06	8.01		7.3		7.3
		Kcl solution method			8.3	5.77	7.6			7.58		7.75	7.79				
	Ignition loss (%)		16.79	17.0	7.9	64.5	21.9	14.5	37.6	11.9	17.6	27.1	16.0		11.57	14.1	32.7
	Organic matter content (%)						50.3				10.5						
	COD <sub>Mn</sub> (mg/g)			112	7.9	2.22		63.7	225	25.0	22.9	109	89.5		57.1	69.4	113
	Nitrogen (mg/kg)			5200	1600	16000	15.9	5614	6290	3000	2700	5510		3700	3800	△950	3600
	Phosphorus (mg/kg)			770	3.73	310	5062		1020	1020	451	540		1200	986	1600	2400
	Sulfide (mg/kg)				0.1	0.4	0.96	0.17	2.28	1.27	6.8	12.1	3.3		4.8	1.04	1.78

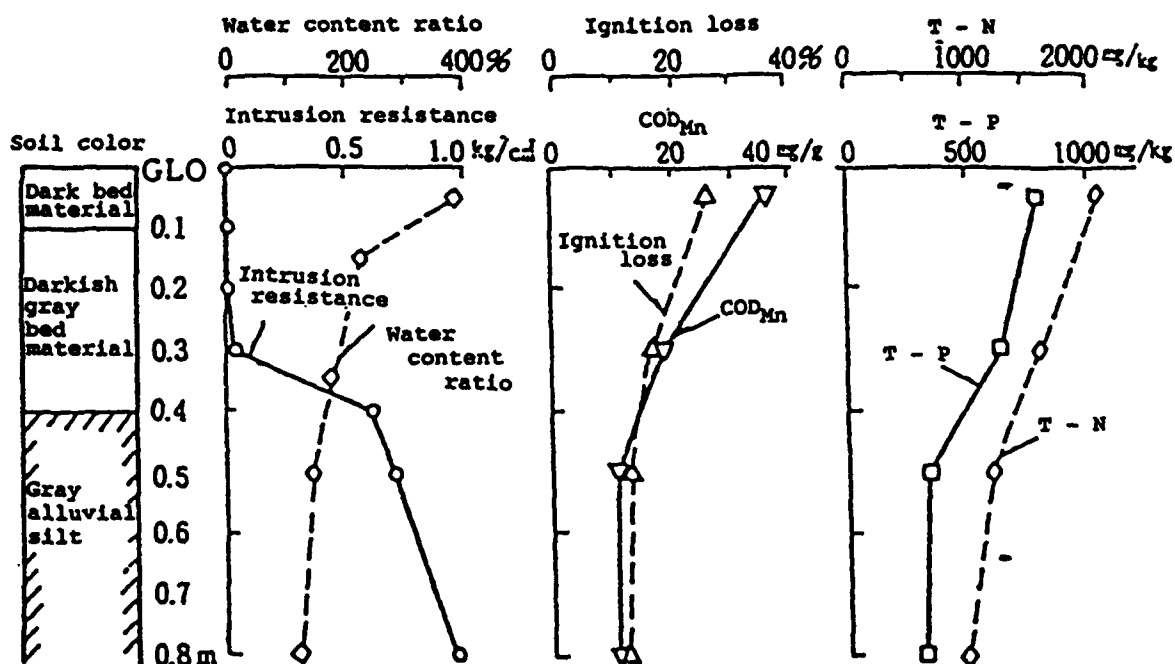


Figure 1. Example of sludge deposit distribution

#### Systems of Treatment and Disposition

Methods of sludge treatment and disposition include such main systems as dredging treatment and reclamation disposal. Subsystems of reclamation disposal include condensation, dehydration, and solidification. These systems are classified in Table 2.

#### Sludge Dredging Technology

##### Problems of Sludge Dredging

Sludge dredging and disposal require continuous work processes of dredging, transport, disposal, and treatment of residual water. For adoption of one dredging method, therefore, its impact on subsequent processes should be taken into consideration. Major points for examination about dredging are listed in Figure 2.

Of the points listed in Figure 2, those specially required for sludge dredging are as follows:

##### a. Dredging of surface-layer sludge.

- (1) Sludge deposits have a tendency to spread thin and wide. At places where the deposits are thick, the removal of surface-layer sludge (containing more pollutants) by sweeping has been often considered in expectation for internal load reduction capacity of water and for cost considerations.

TABLE 2. CLASSIFICATION OF TREATMENT/DISPOSAL SYSTEMS

Main system	Subsystem	Flow
Dredging treatment	Dredging condensation dehydration	<p>1 Pump dredging → Sludge transport → Settling → residual water → Engineering dehydration → Containment → Disposal</p> <p>2 Pump dredging → Sludge transport → Settling → residual water → Engineering or mechanical dehydration → Transport → Disposal</p>
	Dredging dehydration	<p>3 Grab dredging → Sludge transport → Engineering dehydration → Containment → Disposal</p> <p>4 Grab dredging → Sludge transport → Engineering or mechanical dehydration → Transport → Disposal</p>
	Dredging condensation solidification	<p>5 Pump dredging → Sludge transport → Settling → residual water → Solidification → Transport → Disposal</p> <p>6 Pump dredging → Sludge transport → Settling → residual water → Solidification → Transport → Disposal</p>
	Dredging solidification	<p>7 Grab dredging → Sludge transport → Solidification → Containment → Disposal</p> <p>8 Grab dredging → Sludge transport → Solidification → Transport → Disposal</p>
	Dredging special treatment	<p>9 Dredging → Sludge transport → Incineration or burning → Transport → Effective utilization</p>

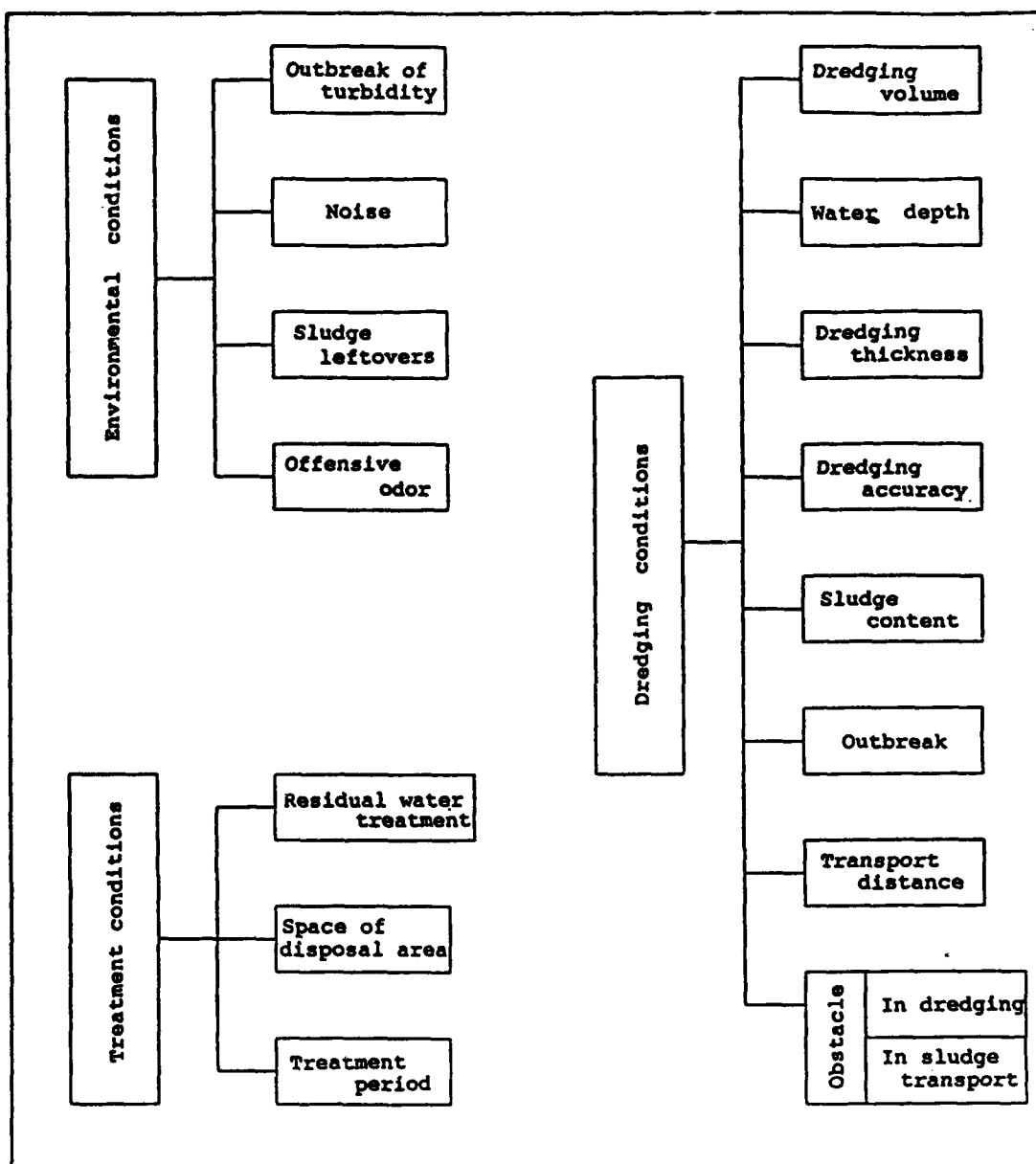


Figure 2. Problems of sludge dredging

- (2) The target layer of sludge dredging, therefore, is thinner than that of conventional dredging, and the development of technology for surface-layer dredging is required.

b. Accuracy of dredging.

- (1) What is handled in sludge dredging is the deposit of sludge harmful to the environment. It is necessary, therefore, to completely satisfy the dredging standards specified for the thickness of sludge to be removed and other items. Furthermore, high accuracy in dredging is required in handling of the soft muddy bed and eliminating the possibility of leftovers.

- (2) It is also required to minimize excess excavation in order not to remove a larger volume of earth than planned, because of the difficulty of securing disposal yards, as mentioned below, and other problems.
- c. High-efficiency dredging. It has become difficult in recent years to secure areas for disposal of dredged earth and sand. High-efficiency dredging is required, therefore, to reduce the size of a disposal yard and the volume of dredged earth for more effective treatment of residual water and for quick rearrangement of the work site after dredging.
- d. Countermeasures for turbidity. Occurrence of water turbidity poses problems for engineering works in water areas. Fine particles of mud on the bottom of water bodies are handled in sludge dredging, and dredging technology that can minimize or eliminate the creation of turbidity is required.

### Classification of Sludge Dredging Technology

Improvement of traditional dredging technology and development of new technology and development of new technology have been under way in order to meet environmental requirements accompanying the removal of sludge deposits from water areas.

Classification of dredges and equipment used for sludge dredging is shown in Figure 3.

### Evaluation of Sludge Dredging Technology

Basic functions of dredging are excavation, removal of mud, and discharge. Sludge dredging has an additional requirement (such as dredging of surface-layer sludge, accuracy of dredging, and prevention of turbidity). In order to meet these requirements, the methods of dredge operation should be improved, and a variety of equipment for management of dredging work must be prepared. A comprehensive system of all these functions is necessary for sludge dredging. Evaluation of various dredging methods as shown in Figure 3 has been made on the basis of their functions and problems, and the result of the evaluation is shown in Table 3.

Generally speaking, the pump dredging method, which has been adopted in many types of dredges, is more suitable for sludge dredging than the grab dredging method, as discussed below.

#### a. Measures for surface-layer dredging and accuracy.

- (1) Cutter pump dredgers have been used in many dredging projects. In the case of this type of dredge, the size of the cutter determines the thickness of dredged earth and the accuracy of dredging. Its swing system makes sweep dredging possible, leaving the bottom comparatively level after dredging.

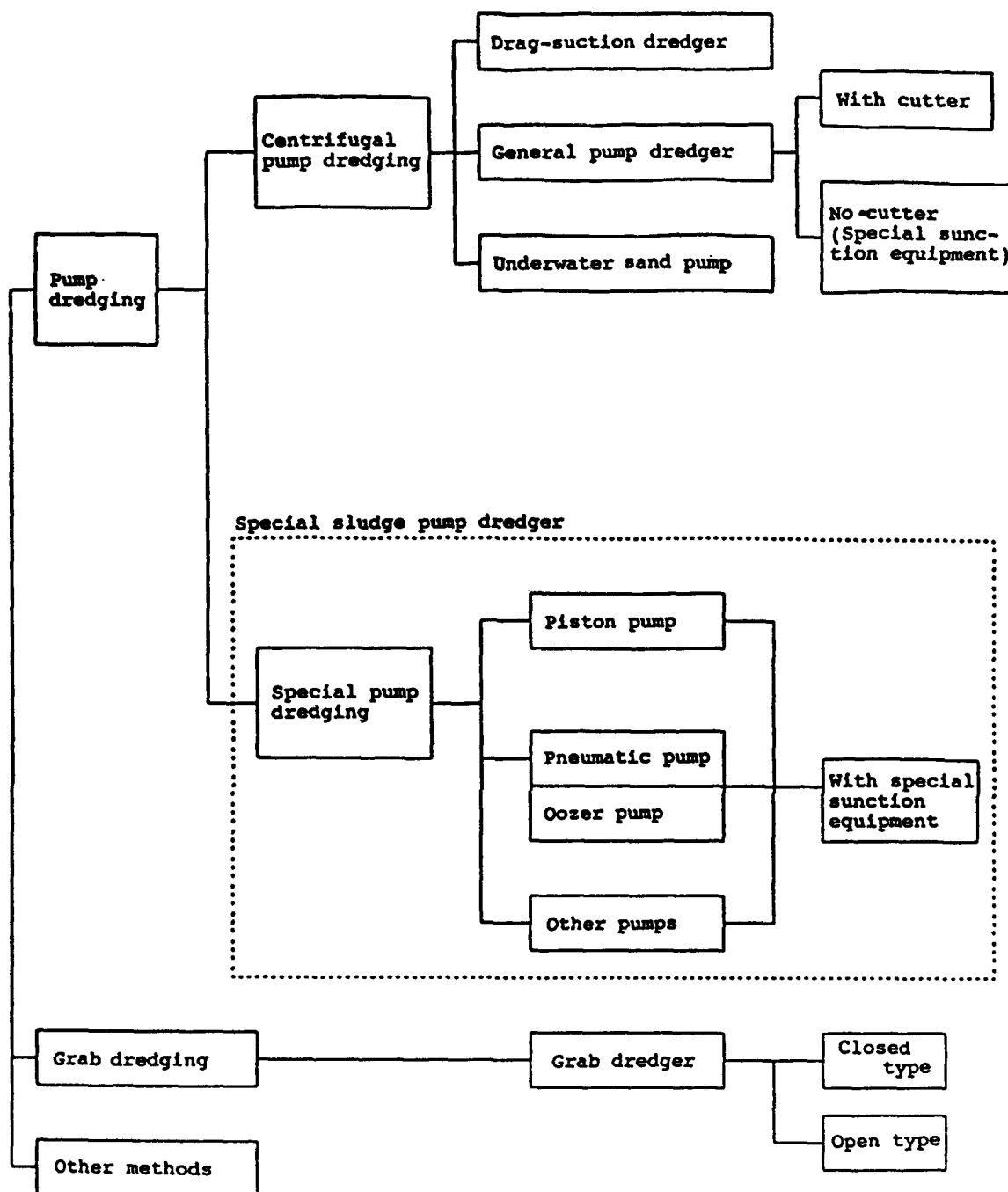


Figure 3. Classification of sludge dredgers

- (2) The cutter dredging, however, is not an ideal method for handling a thin layer of sludge. To solve the problem, the cutter was taken off the pump dredge and replaced by a special suction equipment for more effective utilization of the dredge's earth thickness control equipment and swing system for dredging the thin layer of sludge accurately, as well as for minimizing water turbidity.

TABLE 3. EVALUATION OF SLUDGE DREDGING TECHNOLOGY

Classification of technology	Dredger	Function		Items for evaluation				Operation of dredger	Evaluation
		Excavation (suction)	Dredging / discharge (transport)	Surface dredging	Dredging accuracy	High-efficiency dredging	Outbreak of turbidity		
Pump	Cutter pump dredger	Cutter	Centrifugal pump	△	○	△	△	Swing system (surface sweeping)	○
	Cutterless pump dredger (special suction equipment)	Special suction inlet	Centrifugal pump	⊙	⊙	△	⊙	Swing system (surface sweeping)	⊙
	Special sludge pump dredger piston pump	Special suction inlet	Piston pump (pneumatic removing)	⊙	⊙	○	⊙	Swing system (surface sweeping)	⊙
	Special sludge pump dredger pneumatic pump coarser pump	Special suction inlet	Pneumatic pump/coarser pump (pneumatic removing)	⊙	⊙	○	⊙	Swing system (surface sweeping)	⊙
	Underwater sand pump dredger	—	Centrifugal pump	×	×	×	⊙	Batch system (pit excavation)	×
Grab	Open-type grab dredger	Grab	Barge pneumatic removing others	×	×	⊙	×	Batch system (pit excavation)	×
	Closed-type grab dredger	Grab	Barge pneumatic removing others	×	×	⊙	△	Batch system (pit excavation)	△
	Back hoe / pneumatic removing system	Back hoe	Barge pneumatic removing others	×	×	⊙	×	Batch system (pit excavation)	×
Others	Screw pump / pneumatic removing system	—	Screw Pump pneumatic removing	×	×	⊙	⊙	Batch system (pit excavation)	×
	Vacuum pump / pneumatic removing system	—	Vacuum pump pneumatic removing	×	×	⊙	⊙	Batch system (pit excavation)	

- (3) Grab and backhoe dredging methods, on the other hand, rely on the batch system of pit excavation and are not suitable for surface-layer dredging. These methods also leave the bed ragged after dredging and have problems in accuracy of work.

**b. Measures for high-efficiency dredging.**

- (1) Some pump dredges adopt special pumps that have greater capacity of mud suction when compared with conventional centrifugal pumps. These dredges also use the air-pressure discharge system capable of comparatively long-distance transportation of high-density slurry in order to maximize the mud suction capability of special pumps.
- (2) Grab dredges, on the other hand, are highly efficient in dredging but have problems in accuracy and creation of water turbidity. Closed-type grabs take in more residual water than open-type grabs, and these require additional measures for water draining.

- c. Countermeasures against occurrence of turbidity.** Pump dredges are remodeled from cutter type to cutterless type equipped with special suction inlet; grab dredges are remodeled from open type to closed type, in order to control the occurrence of water turbidity during dredging work.

### Sludge Dehydration Technology

Dredged sludge is generally transported to a disposal site established near the dredging site and utilized as materials for a variety of purposes as shown in Table 4, even if its property is not good.

A disposal site that receives dredged sludge directly may become a final disposal area or play the role of an intermediate treatment area when there is a final disposal area set up elsewhere.

Since sludge dredging works in recent years are suffering from an acute shortage of sludge disposal sites, and more frequent use of intermediate treatment sites, reduction of the volume of sludge, and other methods are under intensive study. To attain these goals, the sludge dehydration technology including the drying bed method is believed to play the most important role.

The dehydration technology is classified into mechanical dehydration and engineering dehydration, with further details shown in Figure 4.

#### MECHANICAL DEHYDRATION METHOD

##### Outline of Method

This method of dehydration by machinery is different from the engineering methods of surcharge, consolidation promotion, and drainage. The mechanical dehydration system consists of a combination or combinations of machines

TABLE 4. DISPOSAL OF DREDGED SLUDGE

Disposal	Feature	Treatment
Reclaiming disposal (both in water area and on land)		
Development of parks, athletic grounds	<ul style="list-style-type: none"> <li>• Suitable for large-quantity disposal.</li> <li>• In the case of noxious sludge, pollution by oozing out should be prevented.</li> </ul>	After application of engineering dehydration or chemical solidification, cover it with good-quality soil of about 1 m thick.
Development of industrial and residential areas	<ul style="list-style-type: none"> <li>• Suitable for large-quantity disposal.</li> <li>• The ground should be firmer than in the case of parks and athletic grounds.</li> <li>• In the case of noxious sludge, pollution by oozing out should be prevented.</li> </ul>	(Same as above.)
Development of farming land	<ul style="list-style-type: none"> <li>• Suitable for large-quantity disposal.</li> <li>• When large quantities of organic matters are included, initial fertilization is not necessary.</li> <li>• Noxious sludge is not suitable.</li> </ul>	Prepare the soil for planting after application of engineering dehydration.
Additional soil to farming land	(Same as above.)	Prepare the soil for planting after application of air drying, drying bed dehydration and engineering hydration in heaps of about 10 cm.
Material for embankment Material for roadbed	<ul style="list-style-type: none"> <li>• Suitable for sludge containing less organic matters.</li> <li>• When used with high water content, later contraction may pose a problem.</li> </ul>	Drying bed dehydration, or chemical solidification.

TABLE 4. (CONCLUDED)

Disposal	Feature	Treatment
	<ul style="list-style-type: none"> <li>• In the case of noxious sludge, pollution by oozing out should be prevented.</li> </ul>	
Material for backfilling	(Same as above.)	Fill in the soil in slurry condition after adding solidification agents.

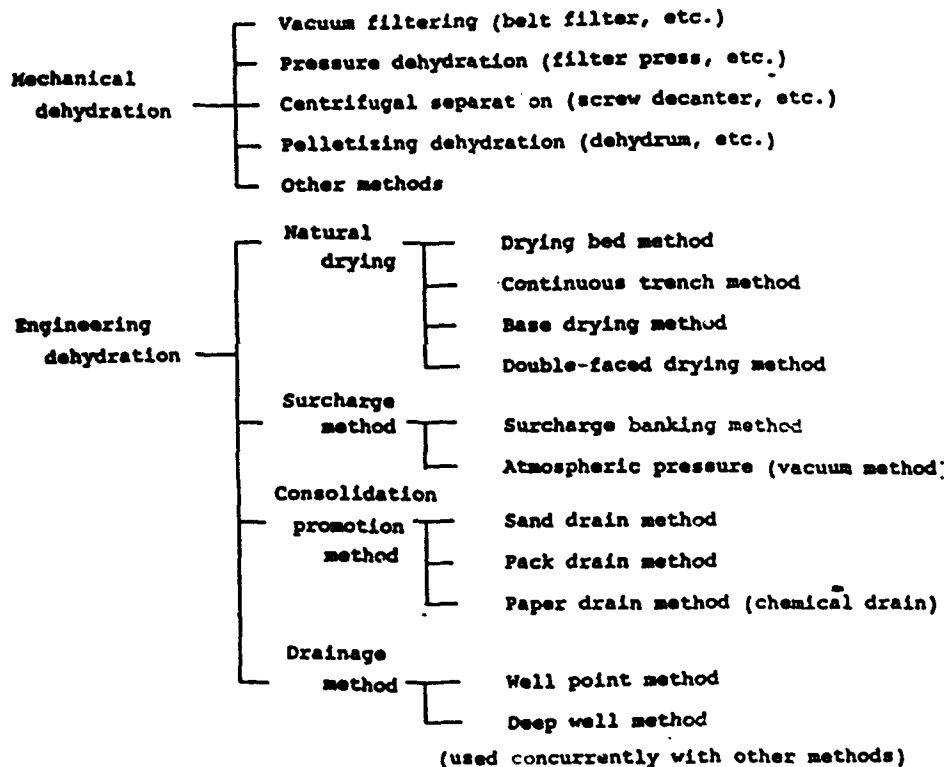


Figure 4. Dehydration methods

and equipment, is transportable, and requires a smaller space than engineering dehydration methods. Figure 5 presents a flowchart of the processes of this treatment system.

What plays the central role of the mechanical system is a dehydrator. Thus, the first step in the development of this method was the selection of a most appropriate dehydrator. As a result and as shown in Table 5, adoption of a centrifugal dehydration system was decided in view of the space required for its installation, continuity, and dredging capacity. The centrifugal

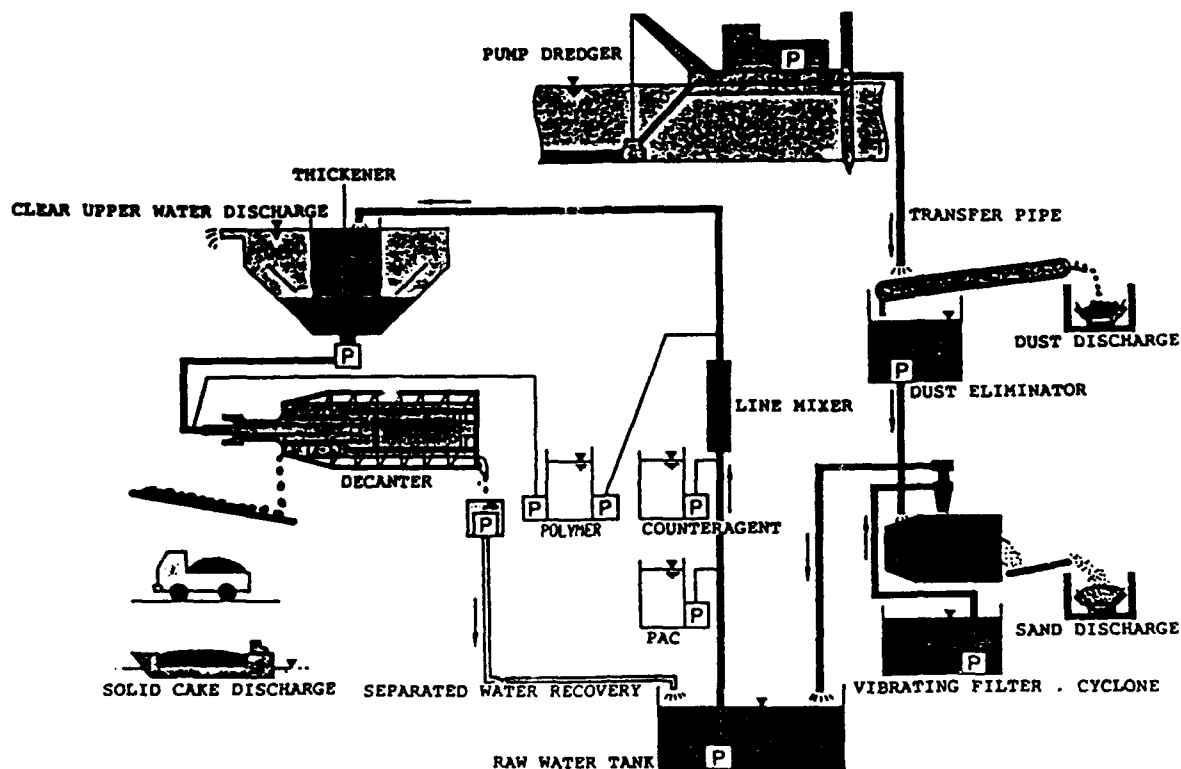


Figure 5. Treatment system flowchart

dehydration system, however, had been adopted in a few cases of engineering works in the past, and many experiments were necessary to ascertain the performance of this system. Finally, a system consisting of a centrifugal dehydrator and auxiliary, peripheral equipment has been developed as a plant which can maximize the capacity of the centrifugal dehydrator.

#### System Apparatus

##### Dust Eliminator

This equipment continually removes pieces of wood, vinyl, or polyethylene bottles and other dusts from slurry. Removed dusts are carried by a belt conveyor installed underneath the eliminator to a garbage yard or a hopper. This eliminator is used to remove coarse rubbishes and prevent choking of the duct system of the treatment plant.

##### Vibrating Filter/Cyclone

The equipment is used to eliminate sand from the slurry which contains soil particles and liquid only after elimination of dusts. This combination of a filter and a cyclone is installed over the top of a water tank. First, coarse sand is sieved out by rough meshes of the filter, and the slurry now containing fine sand, silt, and finer particles only is dropped into the water tank to be sent to the cyclone by an underwater pump. The liquid cyclone by its centrifugal force separates the slurry into two parts, one containing silt

TABLE 5. DEHYDRATORS

Name	Cake water content	Filtrate turbidity	Installation space	Production volume	Continuity	Operation	Rough sketch
Vacuum filter	High	Medium	Large	Large	Yes	Good	
Filter press	Low	Small	Medium	Small	No	Bad	
Centrifugal separator	Medium	Large	Small	Large	Yes	Good	
Belt press	Low	Medium	Medium	Medium	Yes	Bad	
Pelletizing dehydrator	High	Medium	Small	Large	Yes	Good	

and finer particles and the other containing fine sand. The slurry containing silt and finer particles overflows into the raw water tank. The slurry containing fine sand is filtered through finer meshes of the filter, and the fine sand particles sieved out are discharged. Sand particles are separated and discharged in order not to damage the centrifugal dehydrator (decanter), which is designed to dehydrate silt and finer soil particles.

#### Raw Water Tank

This tank is used to temporarily store the slurry overflowing from the liquid cyclone. The stored slurry is pumped out to the thickener.

#### Thickener

This equipment will separate the slurry sent from the raw water tank into clear water and the sludge formed by flocks of soil particles. The separation is done by the addition of flocculant (inorganic and high-polymer type) to the slurry. As the addition of inorganic flocculant acidifies the slurry, the pH-adjusting agent is also added. Upper clear water satisfying discharge standards is discharged. Sludge settling down on the bottom of the thickener is assembled in the center of the bottom by a sludge scraper and sent to the centrifugal dehydrator by a sludge pump. The basic principle of mechanical dehydration is sedimentation of soil particles. The higher the density of slurry by natural settling before separation by a centrifugal dehydrator, the lower will be the water content ratio of the solid cakes and the cost.

#### Centrifugal Dehydrator

This machine will separate the slurry of high density into liquid and solid cakes of silt by the centrifugal effect of high-speed rotation. To promote the effect of dehydration, high-polymer flocculant is added to the slurry again at this stage.

The structure of a screw-decanter type centrifugal dehydrator is shown in Figure 6.

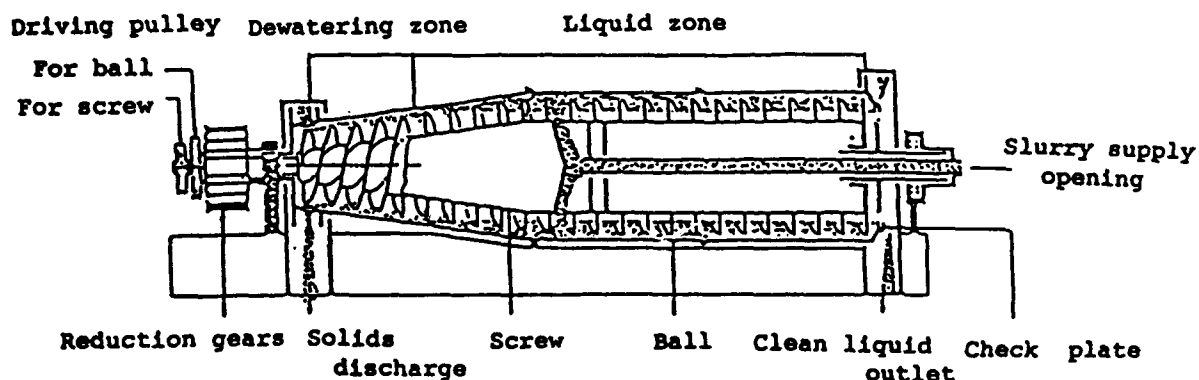


Figure 6. Cross section of screw decanter

A screw decanter is structured to continually separate the liquid with solid particles suspended in it (slurry) into the liquid and solid portions.

A container (bowl) consisting of cylindrical and conical parts and a screw conveyor positioned coaxially inside the bowl rotate in high speed with a small difference of speed, while the slurry is continually supplied into the bowl. The slurry, pushed by centrifugal force, forms a circular pool inside the bowls, and the solid particles suspended in the pool settle outward away from the center to reach the inner wall of the bowl.

The screw conveyor carries these solid particles on the inner wall to the conical part of the bowl, scrapes them up from the pool, and discharges them out of the decanter after further dehydration. At the same time, upper clear water separated from the slurry flows out of the bowl over a barrage at the end of the bowl.

### Basic Characteristics

In order to examine the applicability of the mechanical dehydration method to the dredged slurry of sludge deposits, various experiments using the dehydrator were conducted to ascertain its performance, together with laboratory centrifuge experiments conducted to investigate the conformity of the two sets of experiments.

The flow of the procedures of these experiments and the evaluation of their results is shown in Figure 7, followed by the description of basic characteristics obtained through the experiments using the dehydrator.

Test conditions included factors related to dehydration of dredged slurry such as mechanical factors (centrifugal effect, speed difference, pool depth), discharge, kinds of flocculant (PAC, polymer), and the volume of flocculant addition. The results of these tests show trends of the water content ratio of solid cakes and suspended solids (SS) concentration of separated water.

Details of the test conditions are shown in Table 6, and basic characteristics of the water content ratio of solid cakes and the property of separated water are shown in Table 7.

### Centrifugal Effect

The higher the centrifugal effect is, the greater will be dehydration of solid cakes. Cleanness of separated water reaches its peak at 1,500 G. As shown in Figure 8, solid cakes are scraped up and carried forward by the screw conveyor against centrifugal force. A greater centrifugal effect, therefore, prompts the separation by sedimentation but hampers the transportation of cakes at the tapering part, rendering adverse effects on the property of processed water. In view of the above consideration, it is judged that the appropriate centrifugal effect for the slurry tested this time is 1,500 G.

### Difference of Speed

The smaller the difference of speed is, the better will be the property of processed water, but the peak of the improvement comes at about 15 rpm. The property of solid cakes also improves as the difference of speed decreases. When the difference decreases below that limit, however, the power

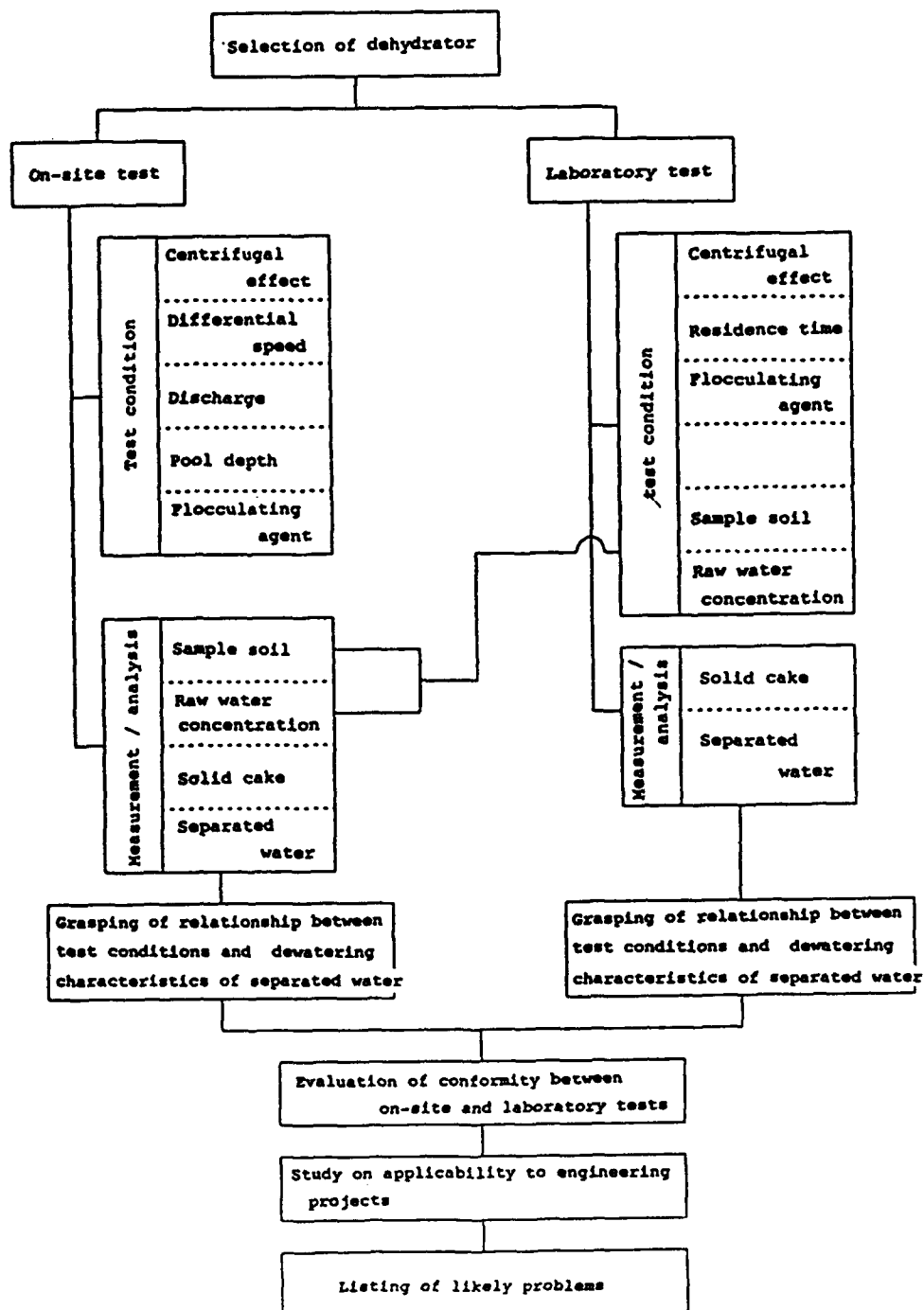


Figure 7. Flow of mechanical dehydration test

TABLE 6. TEST CONDITIONS

Test Condition	Numerical Value
Centrifugal effect (G)	1,000, 1,500, 2,000
Differential speed (rpm)	10, 12, 15, 18.9
Discharge (m <sup>3</sup> /hr)	4, 5, 6, 8, 10
Pool depth (mm)	-0.8, 0.125, 0.8, 10
PAC addition (ppm)	150, 300
Polymer addition (%/DS)	0.075, 0.15, 0.3

TABLE 7. TEST CONDITIONS AND TRENDS OF SLUDGE CAKE/SEPARATED WATER CHARACTERISTICS

Test condition	Sludge cake Water content	Separated water SS	Trend
Centrifugal effect			<p>The higher the centrifugal effect, the better the dehydration of cakes. The volume of suspended matters shows the best value at 1,500 G and indicates no marked changes at higher G levels.</p>
Differential speed			<p>The smaller the differential speed, the better the dehydration of cakes; but the volume of suspended matters indicates the best value at 15 rpm. The trend is conspicuous in the range from 15 to 20 rpm.</p>

TABLE 7. (CONCLUDED)

Test condition	Sludge cake Water content	Separated water SS	Trend
Discharge			Changes in discharge have no impact on the water content of cakes and the volume of suspended matters.
Pool depth			The deeper the pool, the worse the dehydration of cakes but the better the quality of processed water.
PAC addition			Dehydration of cakes is better at 300 ppm of PAC but the change in PAC ppm figures has no marked impact on the volume of suspended matters.
Polymer addition			Dehydration of cakes shows the best value at the range of 0.3 to 0.5%/DS. The volume of suspended matters indicates the best value at the range of 0.075 to 0.15%/DS and the value deteriorates as the polymer volume increases.

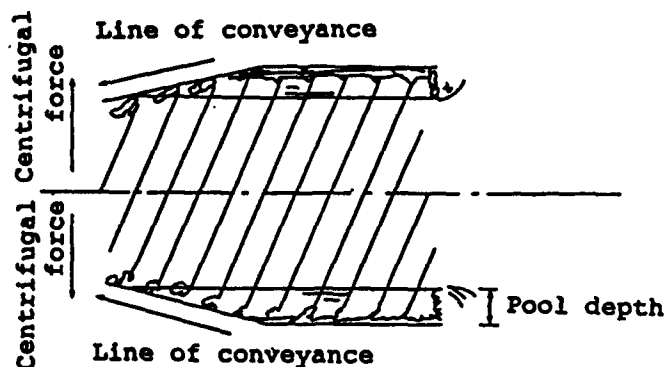


Figure 8. Illustration of effects of centrifugal force

of the screw conveyor is lowered, and cakes that are left behind affect the property of processed water adversely in the form of increased turbidity. When the difference of speed becomes greater than the level, churning by the screw conveyor takes place to hamper separation by sedimentation and to give adverse effects on the properties of cakes and processed water. Thus, it is judged that the appropriate value of speed difference is 15 rpm.

#### Discharge

Changes in discharge have no conspicuous effects on the properties of solid cakes and processed water. Usually, the properties of cakes and processed water deteriorate when the volume of discharge increases, but such a tendency was not recognized in experiments at this time. It is considered that the dehydrator can handle a greater volume of discharge than the test volume.

#### Pool Depth

The deeper the pool becomes, the worse will be the dehydration of cakes but the better the property of processed water. When the pool becomes deeper, the residence time (treatment time) becomes longer to promote the settling of particles and improve the quality of processed water. When the pool becomes deeper, however, the barrage also becomes higher to limit the space of the tapering part where the dehydration process takes place, resulting in poor dehydration of solid cakes.

#### Pac Addition

Changes in the volume of PAC addition have no noticeable effects on the quality of processed water, but its increase (300 ppm) favorably affects the quality of solid cakes. In other words, the settlement of particles in the upper clean liquid becomes sufficient at PAC 150 ppm.

#### Polymer Addition

The property of processed water shows the best value at about 0.15 percent of polymer and that of solid cakes improves as the volume of polymer addition increases. It is considered that the effect of flocculating

agents (including PAC) on processed water in the decanter becomes the best at the volume of that percentage.

## EXAMPLE APPLICATIONS

### Land Plant System

#### Outline of Project

- a. Project name---Barato River dredging project.
- b. Work site---Ishikari-machi, Ishikari-gun, Hokkaido.
- c. Work period---September to November 1988.
- d. The work consisted of the dredging organic sludge deposits in the Ibara-to River using an oozing pump dredge and the transport/discharge of the dredged slurry to an adjacent mud discharge lagoon set up on land. Also established in the discharge area are settling and filtering lagoons for treatment of separated residual water. Dredged slurry is dried for about a half year by natural drying until the start of the next year's work and then loaded in dump trucks for transportation to final disposal areas.

#### Treatment by Mechanical Dehydration

A bifurcated pipeline was set up at the middle of the slurry pipeline of the dredge to continuously take in the slurry (80 to 100 m<sup>3</sup>/hr) to a dehydration plant on land for treatment. Solid cakes and separated water were discharged into the lagoon. Solid cakes were also loaded on dump trucks directly at the plant for transportation to final disposal areas. The arrangement of the plant is shown in Figure 9. (See also Photos 1-3.)

- a. Treatment capacity. Average results of treatment of the dredged slurry, solid cakes, and separated water are shown in Table 8.
- b. Characteristics. The annual average of dredging production in this work is estimated at 80,000 m<sup>3</sup> and that of the water content ratio in original conditions at 300 percent. On these assumptions, the performance of the mechanical method was compared with that of the conventional method.
  - (1) Reduction of work area. The area required for a mud discharge lagoon in the conventional method is 40,000 m<sup>3</sup>. When the mechanical method is adopted, the plant yard of 1,200 m<sup>3</sup> is enough for the treatment of the same amount of dredged slurry.
  - (2) Reduction of dredged slurry volume. After 6 months of natural drying of the conventional method, the water content ratio of the mud was 225 percent, representing a reduction in quantity by 0.63 per cubic meter of original slurry. The mechanical method scored a sand water content ratio of 25 percent and clay (solid cake) water content ration of 130 percent. These

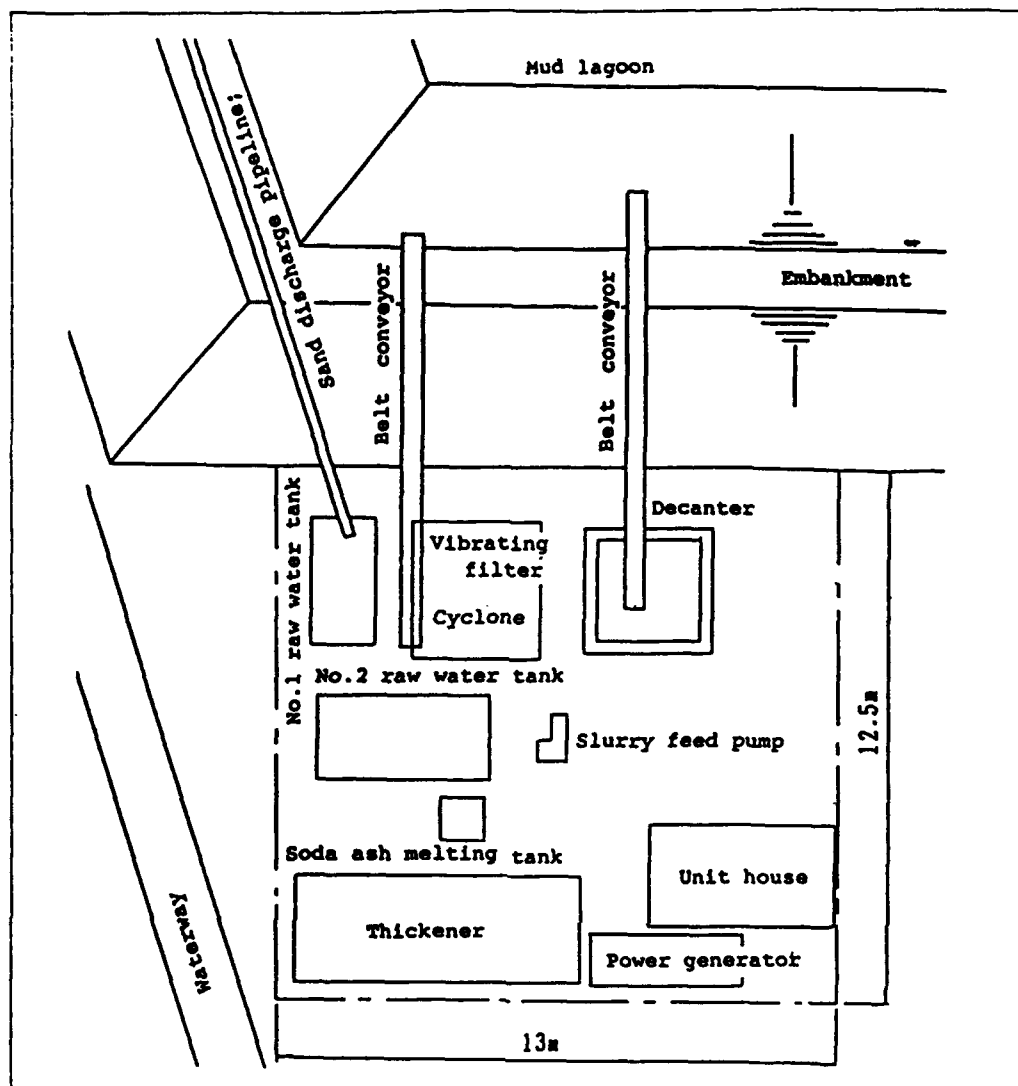


Figure 9. Plant arrangement

figures represent an average reduction of 0.37 per cubic meter of original slurry.

- (3) Continuity of work. Due to the length of time required for natural drying, disposal of sludge has to be done in the next year of the dredging work. The mechanical method makes continuous work possible, ranging from dredging to the final disposal.
- (4) Reduction of sludge disposal volume. The volume of sludge disposal is estimated at 50,400 m<sup>3</sup> for the conventional method and at 29,540 m<sup>3</sup> for the mechanical method, both against the original slurry of 80,000 m<sup>3</sup>.

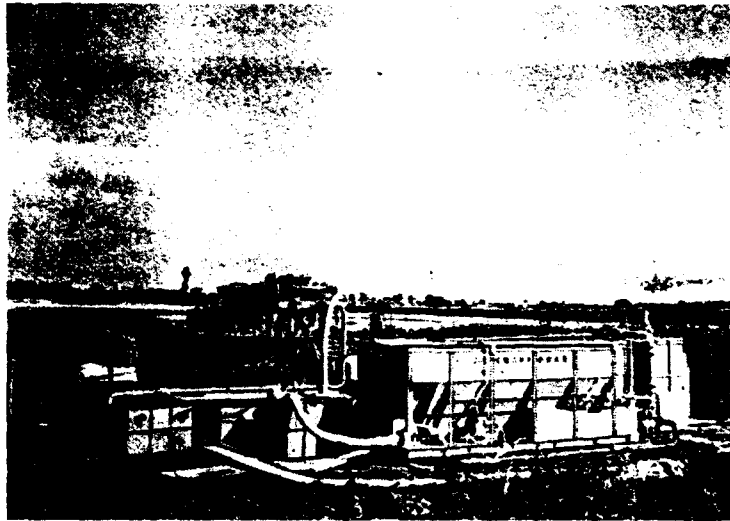


Photo 1. Land dehydration plant

### Floating Plant System

#### Outline of Project

- a. Project name--Tate River dredging project.
- b. Work site--Tatekawa, Sumida-ku, Tokyo.
- c. Work period--January 1989.
- d. Contents of work. A 200-ps micropump dredge was used to dredge the deposits of organic sludge. Dredged slurry was loaded on barges which carried the load to the earth and sand disposal area inside the central breakwater for final disposal.

#### Treatment by Mechanical Dehydration

A bifurcated pipeline was constructed in the middle of the slurry (20 to 50 m<sup>3</sup>/hr) to the floating dehydration plant for treatment. Solid cakes were loaded on the barge, and separated water was discharged into the river. The arrangement of machinery and tools in the floating plant is shown in Figure 10.

- a. Treatment capacity. Average results of treatment of the dredged slurry, solid cakes, and separated water are shown in Table 9.
- b. Characteristics.
  - (1) Reduction of barges and frequency of transport. The work site, located in the midst of a big city, was surrounded by densely built-up areas close to the riverbanks, and the work space was very limited, with river traffic hindered by a leg of a highway



Photo 2. Discharge of solid cake



Photo 3. Loading of solid cake on dump truck

TABLE 8. RESULTS OF TREATMENT UNDER  
LAND PLANT SYSTEM

Item	Treatment Result
Dredged slurry	
Gravimetric concentration	1.9 ~ 11.0 wt%
Particle Size	
Sand	1.0 %
Silt	94.4 %
Clay	4.6 %
Solid cake	
Water content ratio	130 %
Discharged water	
Suspended solids	25 mg/l

bridge standing in the middle of the river. Transportation of dredged slurry was limited to water transport (by barges), and many barges were required to handle the great quantities of dredged slurry produced continuously. The floating dehydration plant continuously separated the slurry into liquid and solid parts, discharging the liquid into the river. Such a plant can greatly reduce the volume of slurry for transport, thus cutting the required number of barges.

- (2) Increased efficiency and continuity of work. Traffic congestion on the river obstructed the operation of barges by limiting the number of barges that could operate at one time. Accordingly, the dredge was sometimes forced to stop its dredging operation. Dehydration treatment on a floating plant makes possible continuous loading and transportation by a small number of barges.

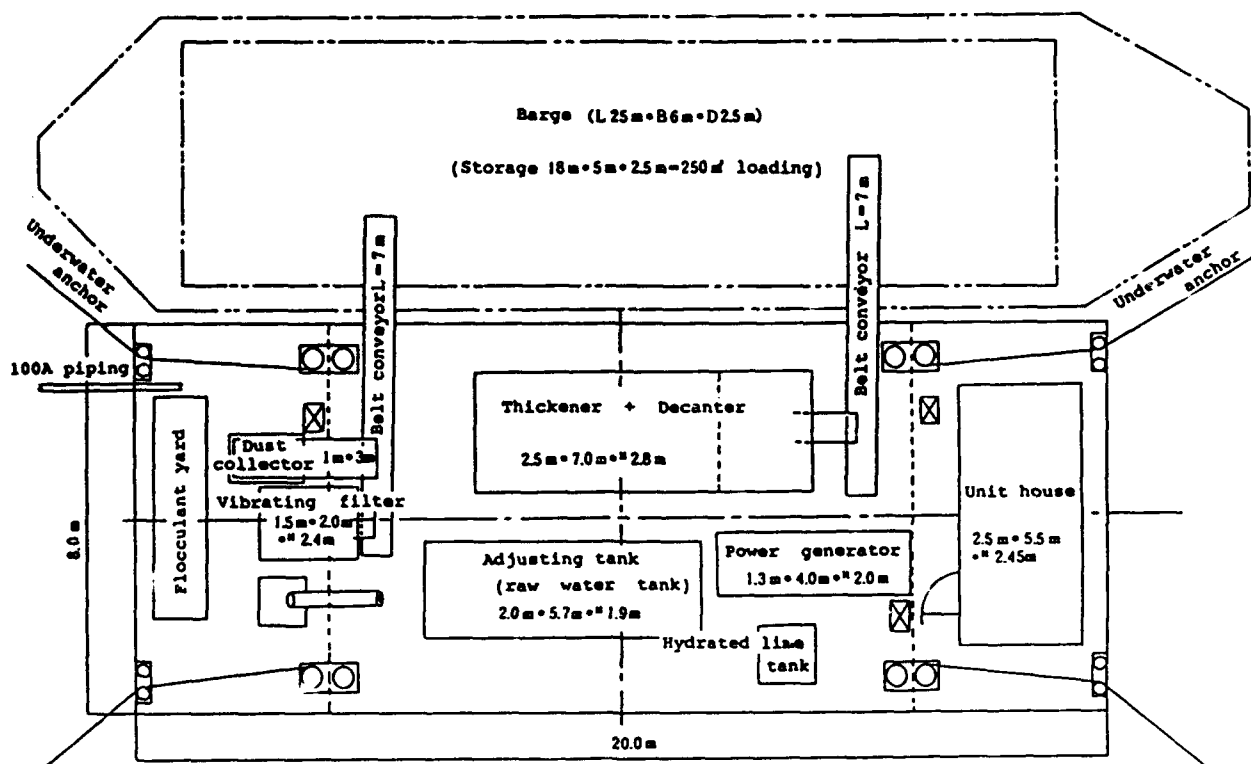


Figure 10. Floor plan of floating dehydration plant undercarriage

TABLE 9. RESULTS OF TREATMENT UNDER FLOATING LAND PLANT SYSTEM

Item	Treatment Result
Dredged slurry	
Gravimetric concentration	3.44 ~ 9.54 wt%
Particle Size	
Sand	35.4 %
Silt	39.5 %
Clay	25.1 %
Solid cakes	
Water content ratio	203 %
Discharged water	
Suspended solids	39 mg/l

#### Floating Dehydration Plant

A full-fledged floating plant specializing in dehydration has been built on the basis of experience and technology gained and developed from the use of a simple floating plant consisting of a barge and portable equipment carried on it. Possibilities of operation and movement along narrow rivers were taken into consideration, and a new idea of assembling barges to build a floating plant was adopted.

This floating dehydration plant is an assemblage of eight barges and has been operating in the dredging project in a river (Ohyoko River) in Tokyo since November 1989.

Specifications of this floating plant are shown in Table 10, and its assembly diagram is indicated in Figure 11. (See also Photos 4-8.)

TABLE 10. SPECIFICATIONS OF FLOATING DEHYDRATION PLANT

<ul style="list-style-type: none"> <li>• Size of a barge: W, 6 m × L, 12 m × D, 0.9-2 m × 8 barges (Maximum draft, 1.5 m; maximum height above surface, 2 m)</li> <li>• Size of ship after assembly of barges: W, 12 m × L, 48.5 m</li> <li>• Production capacity: 200 m<sup>3</sup>/hr in slurry</li> </ul>			
Barge No.	Major Equipment Loaded		
1	Crew cabin, about 25 m <sup>2</sup> Material warehouse, about 20 m <sup>2</sup> Auxiliary 10-kVA power generator	1	Toilet
2	Operation room about 11 m <sup>2</sup> Main 750-kVA power generator 3-t ship operation winch A set of pumps	1 2 1	Fuel tank 7 m <sup>3</sup> Inorganic flocculant tank 10 m <sup>3</sup> Hydrated lime tank 3 m <sup>3</sup>
3	Centrifugal dehydrator	1	High polymer flocculant tank 6 m <sup>3</sup> × 2
4	Various discharge conveyor A set of pumps	6 1	
5	Dust collector Vibrating filter, cyclone Discharge conveyor A set of pumps	2 1 1 1	Compressor 1
6	Raw water tank - 73 m <sup>3</sup> A set of pumps	1	Compressor 1
7	Thickener - 70 m <sup>3</sup>		
8	Slurry pump	1	
Others	Densimeter 2 Surface detector 1 Turbidity meter 2	Flowmeter 5 pH meter 2 Monitoring TV 3	Level meter 13

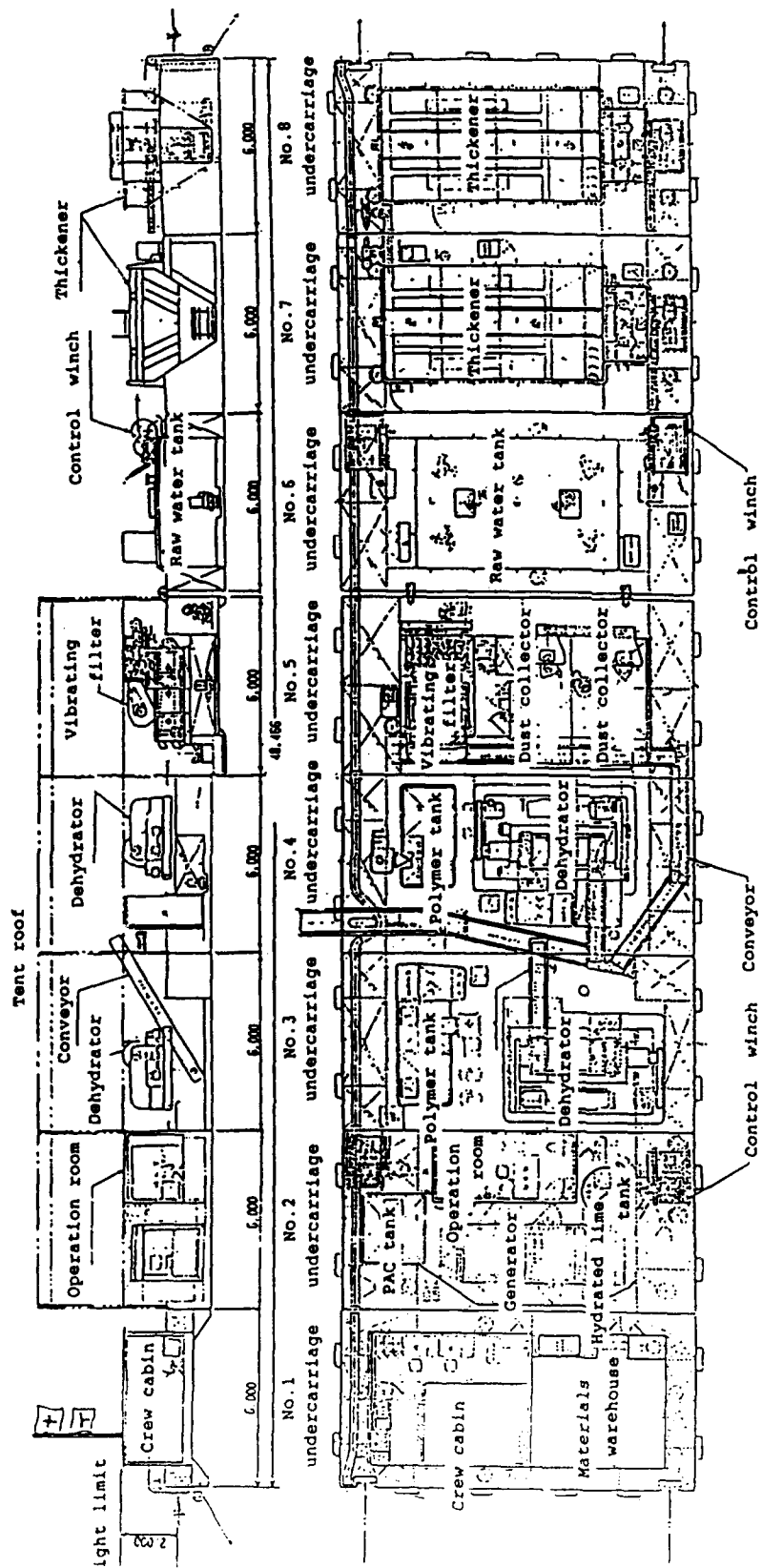


Figure 11. Assembly diagram of floating dehydration plant



Photo 4. Floating dehydration plant

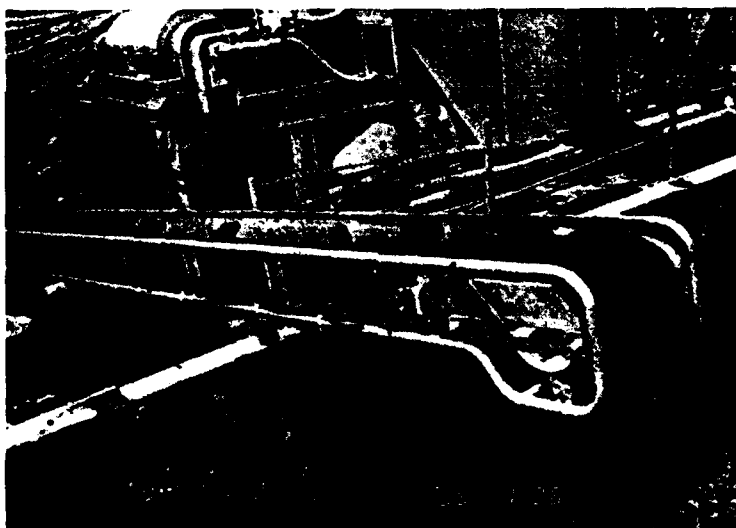


Photo 5. Discharge of solid cake

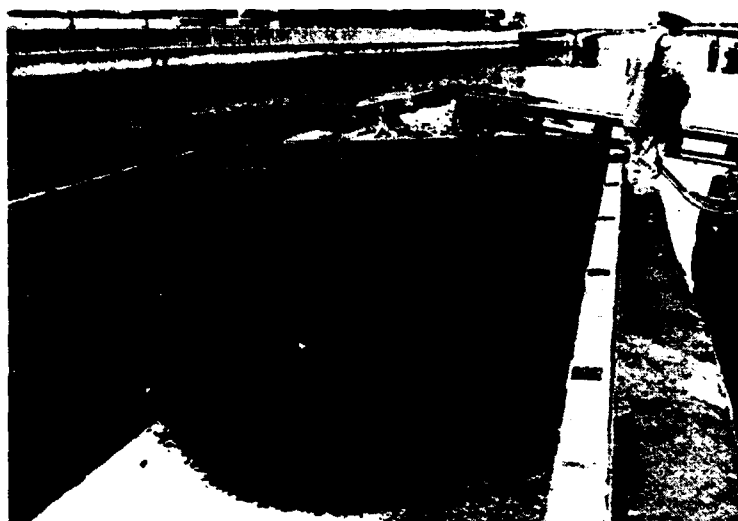


Photo 6. Loading of solid cake on barge



Photo 7. Floating plant specializing in dehydration

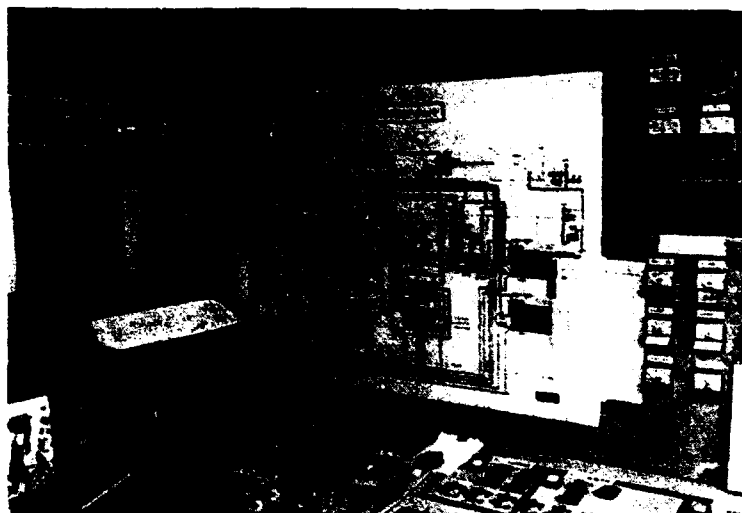


Photo 8. Centralized operation monitoring room

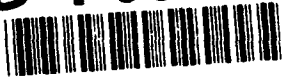
#### CONCLUSION

There have been many occasions where the applicability of mechanical dehydration to works of dredging sludge, earth, and sand was considered seriously. After all, however, attempts to adopt mechanical dehydration for dredging have ended in small-scale experimental projects because of the absence of appropriate dehydrators for dredging plus cost considerations.

Cases of mechanical dehydration treatment introduced in this report have many characteristics which can solve many of the problems confronting sludge dredge works. The floating dehydration plant introduced in one of the cases of application is operating at present, and its performance and other features are the subject of our long-term observation and research. On the basis of data thus obtained, improvements will be made for more accurate management on the execution of works, and efforts will be made for the establishment of more reliable methods of dehydration.

INVESTIGATION ON RESUSPENSION OF RIVER SEDIMENTS  
USING THE ANNULAR FLUME  
DURING RAINFALL

AD-P006 459



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ABSTRACT

A long-range study on the hydrograph is necessary in estimating the pollution load from rivers during rainfall. During the heavy rainfall, such a load often corresponds to the total load at the ordinary flow level.

The present study is made to determine the volume of suspended matter during rainfall in an indoor-scale circular waterway (2 m in diameter and centrally driven). The stepwise increase in shearing stress and migration of suspension from the river mouth sediment was already reported using this device.

Further improvement is being made for an experiment under the condition close to heavy rainfall.

INTRODUCTION

The Japan Sediments Management Association was founded 15 years ago. In the first half of these 15 years, our energies were concentrated on the establishment of "know how" regarding the treatment of harmful matters such as T-Hg and PCB for which the tentative national elimination standard was established. In the second half of this period, technologies in the past were reviewed to investigate new fields relating to sediments, chiefly technologies to improve environments such as organic sediments. At the same time, efforts were made to examine the needs of this age including the waterfront, sea blue technologies, etc., and to draw the map of these technologies.

Our basic concepts of sediment purification will be described below. First, the actual state of the vertical distribution of sediments, i.e., the settlement of contaminants was investigated. Second, the elution rate ( $\text{mg}/\text{m}^2/\text{day}$ ) of contaminants from the sediments into water at the indoor level during the contaminant accumulation process was studied, and a plan was made for the sediment removal procedure or other countermeasures, taking into consideration its influences on water quality, or in other words, the contribution to water purification. In recent years, the evaluation of the contribution to water quality purification, particularly in comparison with the inflow load (external load), has often been requested. However, in practice, it is difficult to evaluate such a load accurately. Therefore, it is

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necessary to develop a method to estimate the load at a simple indoor level. For this reason, this subject is selected as one of the themes of our voluntary investigation.

#### OBJECTIVES OF THE INVESTIGATION

In some cases, to estimate the contamination load from a point source and nonpoint source during rainfall, a hydrograph as shown in Figure 1 is investigated. (See also Nikaido 1968.) This investigation should be carried out for a long time, because waiting for rainfall will depend on the weather.

The key points of this estimation are clarification of (a) transport of sediments and (b) the relationship between sediments and water quality. The possibility of grasping these key points by using an annular flume of indoor level was checked.

Figure 1 shows the relationship between shear stress of sediments in harbors and the concentration of suspended matter. It was expected that if intermittent measurement of the everchanging flow of the water was made to assess the water quality, and if the same relationship between sediments and rainfall intensity as noted in the river sediments could be proven onsite, the approximate contamination load could be grasped easily. Figure 2 represents an outline of the contamination load estimation method.

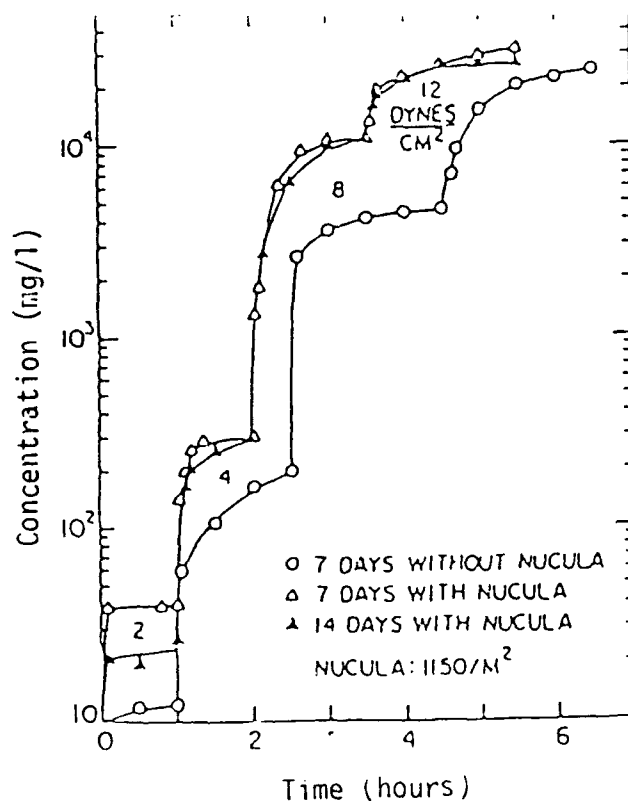


Figure 1. Relationship between rotation time and suspended solids (SS) concentration

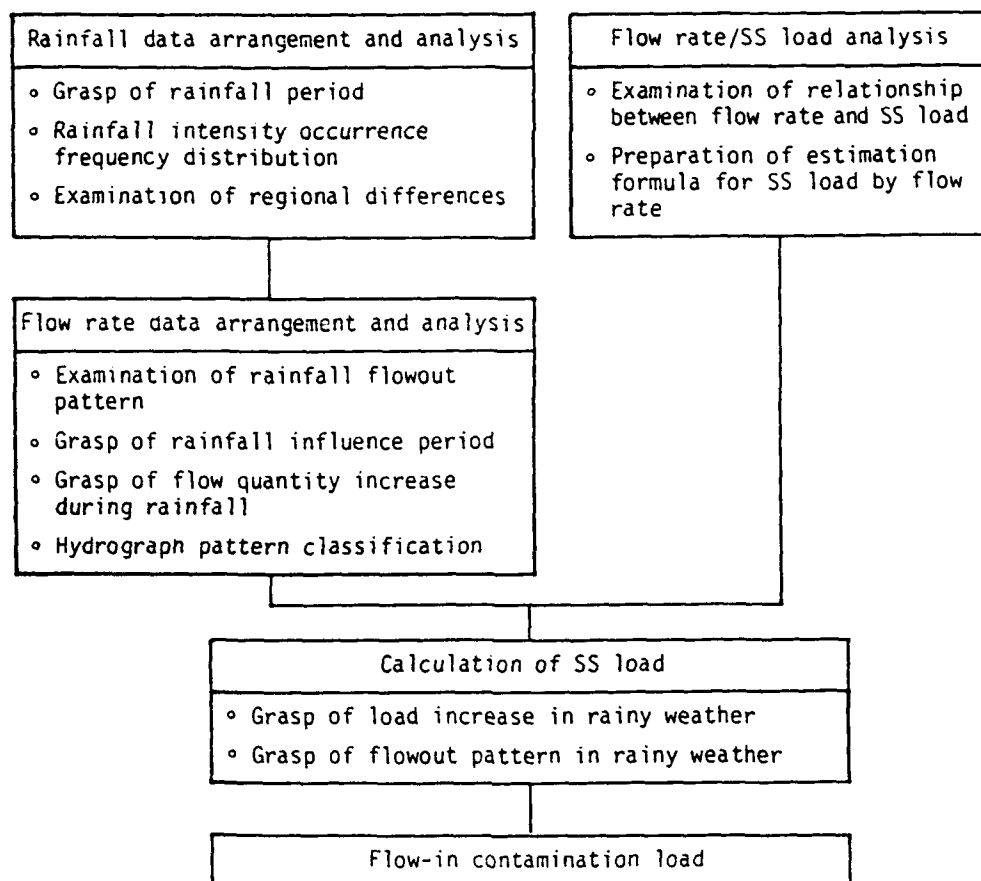


Figure 2. Contamination load estimation method

Incidentally, if the same can be applied to sediments, various problems of sediments can be solved based on something like "sediment reference points." This investigation was made according to such a concept. The relevant literature and the intermediate results of this investigation are described below.

#### EXPERIMENTS ON TRANSPORT OF SEDIMENT PARTICLES USING ANNULAR FLUME

The results of this experiment may be used for the following items:

- a. Estimation of suspended matter concentration and load during rainfall.
- b. Transportation of contamination deposits.
- c. Estimation of settlement properties and resettlement of suspended particles.

### Experimental Equipment

Figure 3 shows the experimental equipment. Photos 1 and 2 illustrate the setup in use. It consists of the annular flume which gives the superficial flow rate by means of the centrally driven shaft-type rotary flat plate. The results of the long-term experiments conducted to estimate the amount of suspended matter from sediments on the bottom of harbors using this equipment were already reported. The dimensions of this experimental equipment were the same as those of the equipment described by Tsai and Lick (1987).

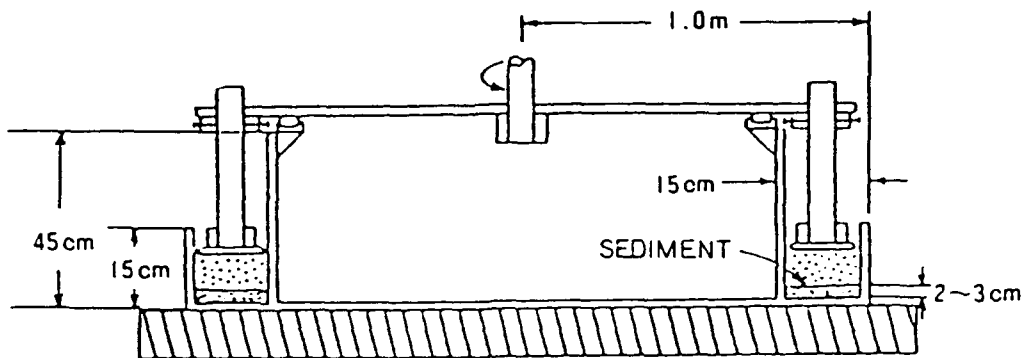


Figure 3. Experimental equipment



Photo 1. Flume with the shear stress generating plate installed (for flow rate measurement)



Photo 2. Overall view of experimental equipment

### Sample

Samples were taken of sediments of rivers at the ordinary water level and during rainfall, as well as contaminated sediments discharged from the river into the lakes.

The resuspension of sediments will be greatly affected by the quantity of flow and flow rate of the rivers as well as their physical and chemical properties. Therefore, it is also important to select samples with different

properties for the investigation. Taking this fact into consideration, the following four samples were used in this investigation.

- a. The Ohhorigawa River (a river flowing into the Teganuma Lake).
- b. The Teganuma Lake (after flowing in).
- c. The Yunoko Lake (after flowing in).
- d. The Tamagawa River.

As for sediments, its water content, particle size, specific gravity, weight per unit volume, ignition loss, COD, T-N, T-P, etc., were measured. As for the water quality, its turbidity, SS, COD (BOD), T-N, and T-P were determined. Figure 4 shows the composition of the particle size.

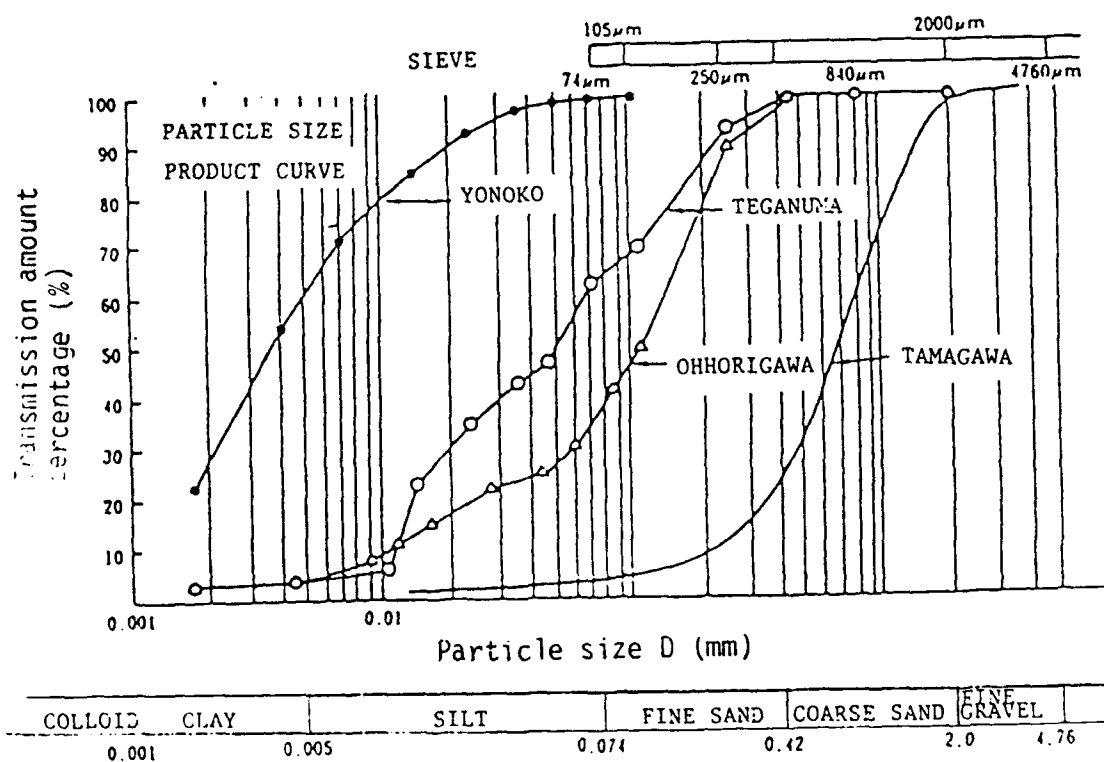


Figure 4. Composition of the particle size

### Method

#### Invariable Overlying Water Depth

The annular flume was filled with superficial sediment (0 to 15 cm) that settled on the river bottom to a depth of 2 to 3 m. Water was poured into the annular flume to provide the depth of about 7 to 8 cm. After the rotary flat plate was driven to give the superficial flow rate adequate time to make the water muddy, the rotation was suspended for 24 hr to let the muddy water sand. After it was confirmed that the suspended matter was stabilized as sediments, the experiment was started.

The concentration of muddy water was adequately adjusted by conducting the preliminary natural settlement test to provide mud to the thickness of 2 to 3 cm after settlement for 1 day.

#### Change in Overlying Water Depth

The water depth was adjusted to 2 cm, 5 cm, and 10 cm, and the flow rate in the annular flume was kept constant.

### Results

#### Properties of the Samples

Table 1 shows the properties of the samples used in this experiment. Table 2 shows the water quality of the supernatant from which the mud was separated in the natural settlement of muddy water.

The important parameters which govern the change from sediments into suspensoid were the composition of particle size (shown in Figure 4) and specific gravity. Sediments of the Yunoko Lake consisted principally of silts and clays, while sands mainly constitute those of the Tamagawa River. Sediment composition of the Teganuma River could be said to be between those of the two described above.

#### Resuspension of Particles at Same Water Depth

Tables 3 and 4 show the experimental results of resuspension of the particles of sediments at four places. The total rotation time of the rotary flat plate was 0 to 235 min. Table 4 shows the flow rate in the annular flume and the water quality of resuspended matter of the Ohhorigawa River, the Teganuma Lake, the Yunoko Lake, and the Tamagawa River.

Figure 5 shows the relationship between rotation time and turbidity.

#### Relationships at Varied Water Depth

Tables 5a-5c show the relationship between the rotation time and turbidity until the flow rate become constant after changing the flow rate. Figure 6 shows those corresponding to respective relationships. The turbidity of water varied greatly according to the water depth. The turbidity at the flow rate of 0.2 m/sec and at the water depth of 2, 5, and 10 cm was 7,000 (150 minutes), 720 (20 minutes), and 200 (10 minutes), respectively. Their ratio was 35:3.6:1. The turbidity of water cannot be simply compared with the total amount of turbid water.

### EXAMPLE OF CONTAMINATION LOAD ESTIMATION

Ordinary sediments of a river are the source of infinite contamination. As an example, estimation of the load of the suspended particles from the closed sewage conduit confluence system due to rainfall is described.

TABLE 1. BASIC PROPERTIES OF THE SAMPLES

<u>Parameter</u>	<u>Yunoko</u>	<u>Ohhorigawa</u>	<u>Teganuma</u>	<u>Tamagawa</u>
Water content (%)	782.6	92.6	239.7	24.5
Specific gravity	2.23	2.65	2.50	2.71
Weight per unit volume (g/cm <sup>3</sup> )	1.08	1.51	1.35	1.29
Ignition loss (%)	13.7	19.9	17.4	1.69
COD (mg/g)	25.0	7.99	12.6	2.0
T-N (mg/g)	7.59	1.85	4.08	0.37
T-P (mg/g)	1.17	3.28	5.33	0.25
pH	6.9	5.4	6.5	6.4

TABLE 2. WATER QUALITY OF SUPERNATANT AFTER  
SETTLEMENT OF MUDDY WATER

<u>Parameter (mg/l)</u>	<u>Yunoko</u>	<u>Ohhorigawa</u>	<u>Teganuma</u>	<u>Tamagawa</u>
Turbidity	16.5	41.0	51.0	450
SS	36.0	78.0	68.0	119
COD	6.6	7.3	11.2	12.2
BOD	2.4	2.1	6.6	5.7
T-N	7.17	3.92	3.90	4.35
T-P	0.08	0.30	0.89	0.54

TABLE 3. EXPERIMENTAL RESULTS

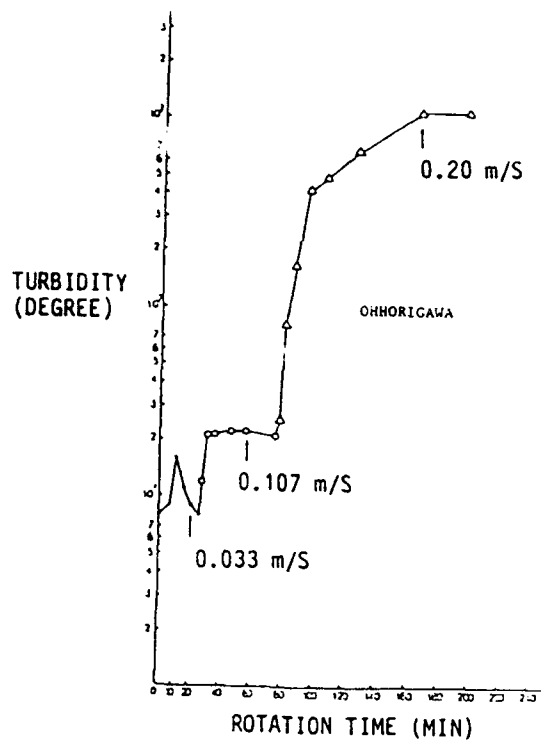
Rotation Time (min.)	Item	Ohhorisawa			Iosokuma			Yunoko			Iomoshima		
		Tur- m/s	bidity m/s	Tur- bidity	Tur- m/s	bidity m/s	Tur- bidity	Tur- m/s	bidity m/s	Tur- bidity	Tur- m/s	bidity m/s	Tur- bidity
0		8.0	-	-	0	5.5	-	0	5.5	-	0	5.5	-
1		-	0.033	12	0.107	25	-	0.033	6	0.107	27	-	0.033
5		9	-	21	-	81	6	100	16.1	45.9	1100	0.033	6
10		16	-	21	-	162	6	130	10.0	61.0	1350	-	-
15		11	-	22	-	-	6	-	12.0	270	-	-	-
20		0.033	9	-	22	405	0.033	6	0.107	6	170	0.033	9.0
25		-	8	-	-	-	6	-	8.0	-	-	-	-
30		-	-	0.107	22	480	-	6	260	-	390	2100	-
50		-	-	-	21	670	-	0.200	220	0.107	400	2300	-
90		-	-	-	-	0.200	1050	-	190	-	400	0.200	2600
120		-	-	-	-	-	1080	-	-	-	-	2800	-
Cumulative total (min)		25	75	195	25	55	145	25	115	235	5	15	25

TABLE 4. RELATIONSHIP BETWEEN FLOW RATE AND  
WATER QUALITY

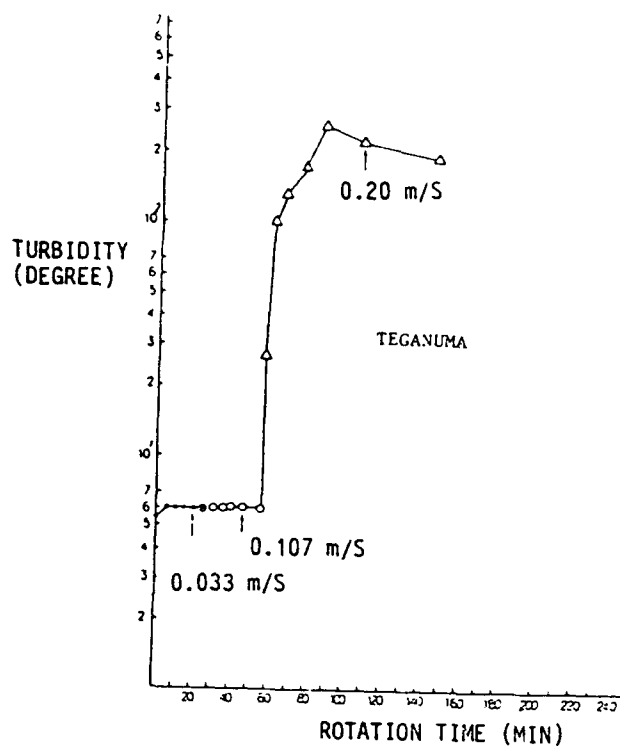
Parameter	Ohhorigawa				Teganuma			
	Blank	1*	2	3	Blank	4	5	6
Flow rate (m/sec)	0	0.033	0.107	0.20	0	0.033	0.107	0.20
Time lapse (min.)	0	25	50	120	0	25	30	90
pH	6.9	7.1	7.2	7.1	7.5	7.1	7.5	7.6
Turbidity (mg/l)	8.0	8.0	21.0	1,080	5.5	6.0	6.0	190
SS (mg/l)	16.0	17.0	40.0	126	8.0	11.0	11.0	266
COD (mg/l)	5.3	5.6	4.8	103	5.3	6.2	5.7	25.6
BOD (mg/l)	1.8	2.5	1.7	8.5				
T-N (mg/l)	3.15	3.33	3.77	9.71				
T-P (mg/l)	0.22	0.20	0.23	10.4				

Parameter	Yunoko				Tamagawa		
	Blank	1	2	3	Blank	12	13
Flow rate (m/sec)	0	0.033	0.107	0.20	0	0.20	0.30
Time lapse (min)	0	25	90	120	0	10	40
pH	7.1	7.5	7.2	7.1	7.5	7.6	7.7
Turbidity (mg/l)	5.5	8.0	400	2,800	5.5	7.0	35.0
SS (mg/l)	3.0	10.0	790	5,370	5.0	7.0	91.0
COD (mg/l)	4.5	5.4	82.0	545	7.8	8.2	12.6
BOD (mg/l)	1.2	2.8	13.5	72.5	1.8	2.3	4.5
T-N (mg/l)	5.71	5.95	15.2	66.3	1.69	1.73	3.03
T-P (mg/l)	0.05	0.05	1.06	1.56	0.48	0.50	0.72

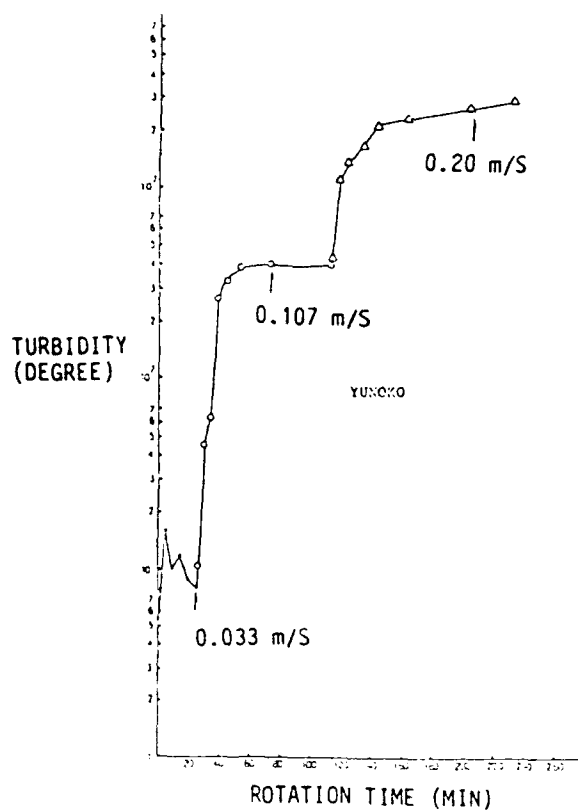
\* Run number.



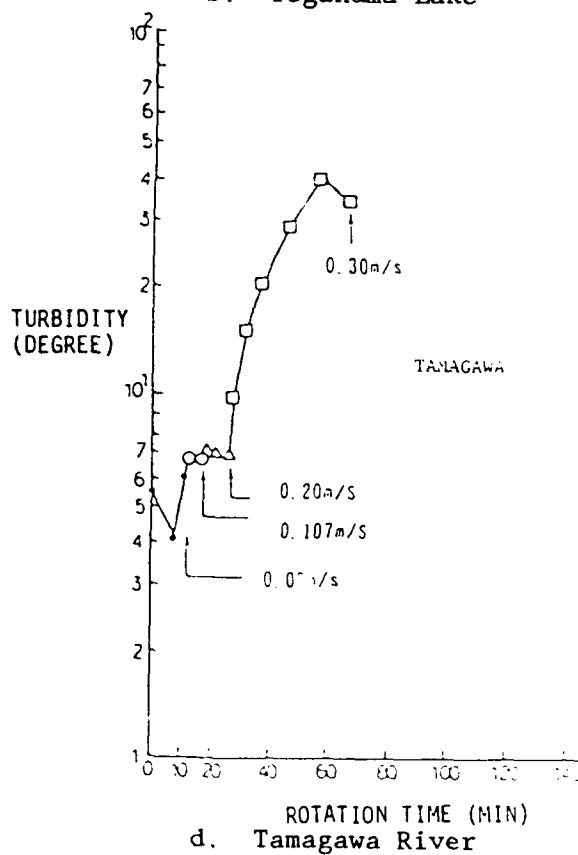
a. Ohhorigawa River



b. Teganuma Lake



c. Yunoko Lake



d. Tamagawa River

Figure 5. Relationship between flow rate and turbidity

TABLE 5a. MEASUREMENT RESULTS OF TURBIDITY IN SEDIMENTS  
RESUSPENSION EXPERIMENT (WATER DEPTH: 2 CM)

Flow Rate (m/sec)	Time Lapse (min.)						
	0	1	3	5	10	20	70
0.033	4.5	100	100	100	100	-	-
0.10	-	400	720	810	960	1,100	1,100
0.20	-	1,500	2,200	2,500	2,900	3,900	4,200

Flow Rate (m/sec)	Time Lapse (min.)						
	40	50	60	70	80	90	100
0.033	-	-	-	-	-	-	-
0.10	1,100	-	-	-	-	-	-
0.20	4,500	4,800	5,000	5,200	5,600	5,800	6,200

Flow Rate (m/sec)	Time Lapse (min.)						
	120	150	180	210	240	270	
0.033	-	-	-	-	-	-	-
0.10	-	-	-	-	-	-	-
0.20	6,600	7,000	7,800	8,400	9,200	9,600	

Note: Values are expressed in milligrams per liter.

TABLE 5b. MEASUREMENT RESULTS OF TURBIDITY SEDIMENTS  
RESUSPENSION EXPERIMENT (WATER DEPTH: 5 CM)

Flow Rate (m/sec)	Time Lapse (min.)						
	<u>0</u>	<u>1</u>	<u>3</u>	<u>5</u>	<u>10</u>	<u>20</u>	<u>30</u>
0.033	8.0	17	16	16	16	-	-
0.10	-	230	280	300	300	300	-
0.20	-	390	470	500	680	720	720

Note: Values are expressed in milligrams per liter.

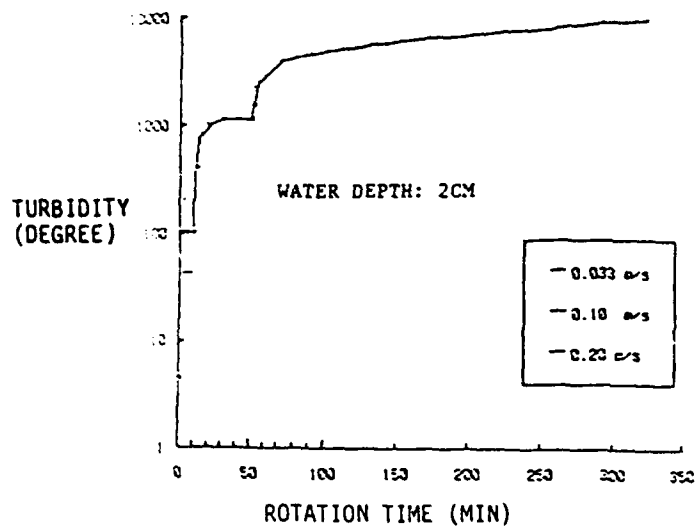
TABLE 5c. MEASUREMENT RESULTS OF TURBIDITY IN SEDIMENTS  
RESUSPENSION EXPERIMENT (WATER DEPTH: 10 CM)

Flow Rate (m/sec)	Time Lapse (min.)				
	<u>0</u>	<u>1</u>	<u>3</u>	<u>5</u>	<u>10</u>
0.033	1.5	-	-	-	1.5
0.10	-	33	52	60	60
0.20	-	120	170	200	200

Note: Values are expressed in milligrams per liter.

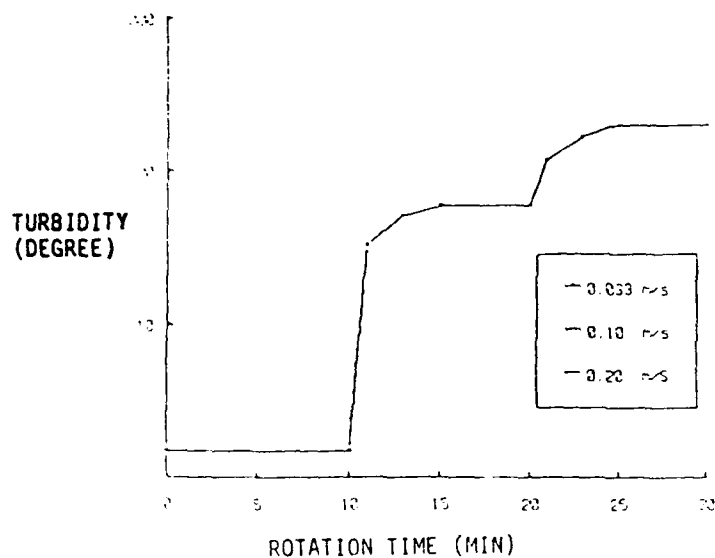
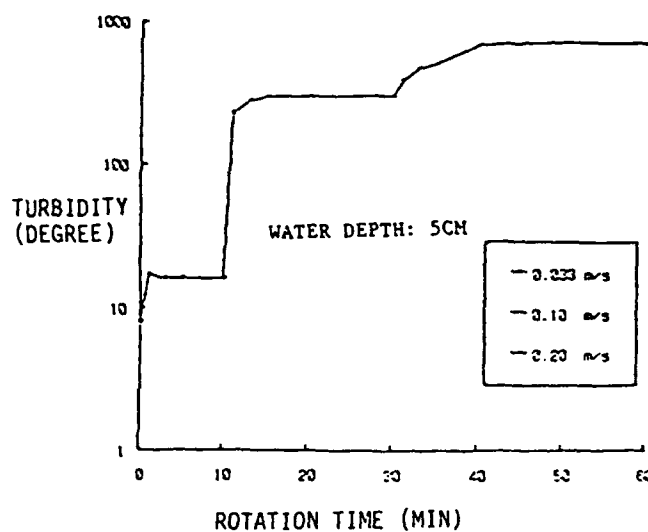
The SS concentration due to rainfall was measured in the overflow from the three closed sewage conduits and at the convergence point downstream (Figure 7). With the increase in the intensity of rainfall, the flow rate increased, but the SS concentration demonstrated a peak regardless of the flow.

If the overflow occurs when the rainfall intensity is 5 mm/hr or more, the average rainfall intensity is about 8.4 mm/hr according to the frequency diagram (Figure 8) of the rainfall intensity in this district, indicating continuous rainfall for 75 hr. The water quantity corresponding to 8.4 mm/hr is approximately 40 m<sup>3</sup>/sec. (This value is estimated from the relationship between the water depth H and the rainfall intensity R, and the relationship between water depth H and the quantity of flow Q.)



a. Water depth: 2 cm

b. Water depth: 5 cm



c. Water depth: 10 cm

Figure 6. Relationship between flow rate and turbidity at variable water depth

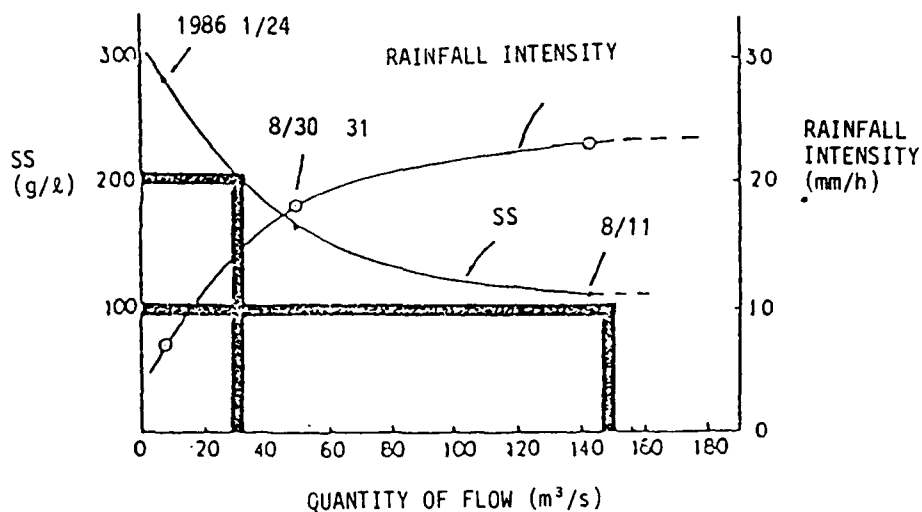


Figure 7. Relationship between flow rate, SS, and rainfall intensity at peak

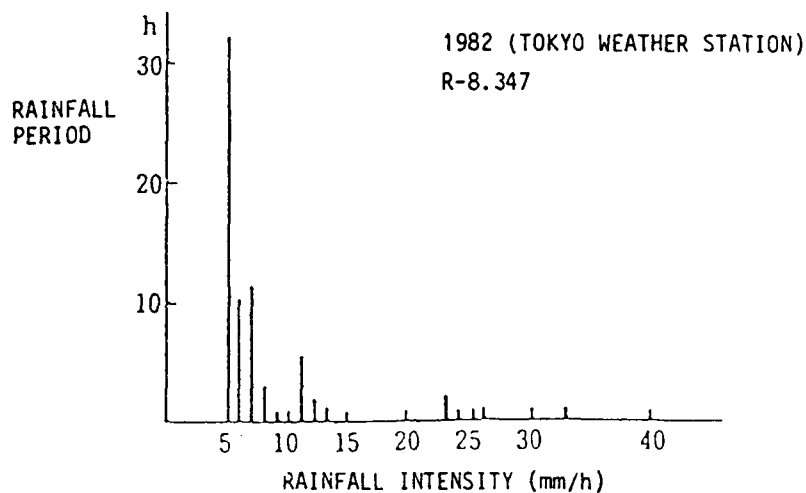


Figure 8. Duration of rainfall in 1982 with intensity over 5 mm/hr

The contamination load  $W$  overflowed by rainfall under this condition is calculated by the formula given below.

$$\begin{aligned}
 W &= 40 \text{ m}^3/\text{sec} \times 180 \text{ g/m}^3 \times 3,600 \times 75 \text{ hr} \\
 &= 25.9 \times 75 = 1,944 \text{ tons/year}
 \end{aligned}$$

If all the contamination load calculated is settled as the sediment, the volume  $V$  becomes  $5,542.3 \text{ m}^3$  when calculated by the formula given below.

$$V = \left( \frac{W}{r_w} + \frac{1}{r_s} \right) \times W = \left( \frac{2.5}{1.02} + \frac{1}{2.5} \right) \times 1,944$$

$$= (2.451 + 0.4) \times 1,944 = 5,542.3 \text{ m}^3$$

It will be necessary to determine the amount of sediment in the rivers and the discharge place. Another subject for future study is the examination method of the conditions to rationally determine the scale of facilities for taking in the overflowed water (Figures 9 and 10).

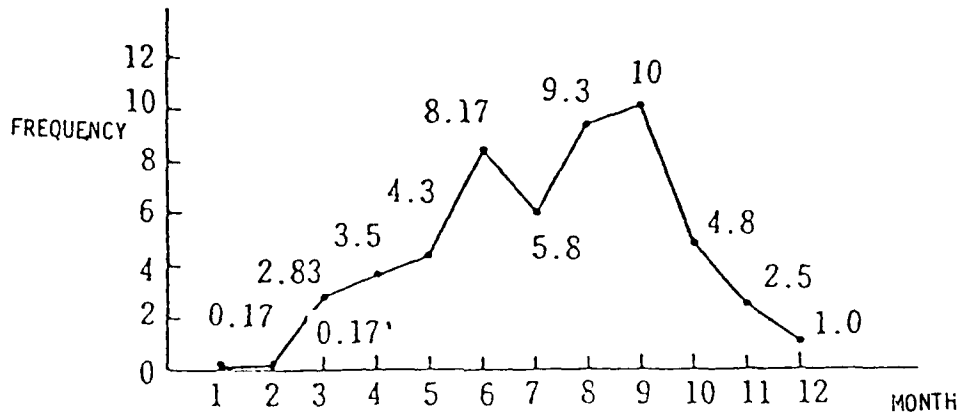


Figure 9. Rainfall depth with intensity over 5 mm/hr

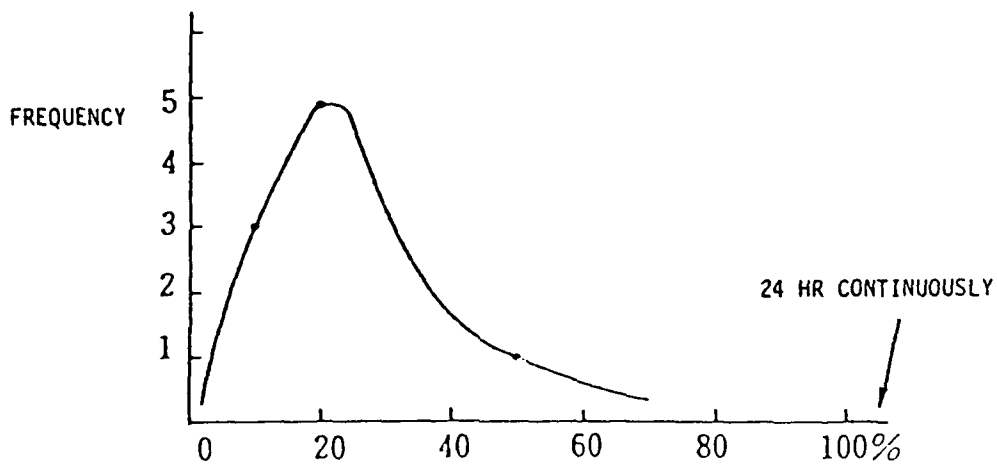


Figure 10. Percentage and frequency of daily continuous rainfall

In Figure 11, the settlement data obtained by the indoor test are plotted against the measured settlement rate during rainfall. The settlement distribution rate is estimated according to that of the similar river. Since data on a large quantity of the rainfall intensity and the quantity of flow

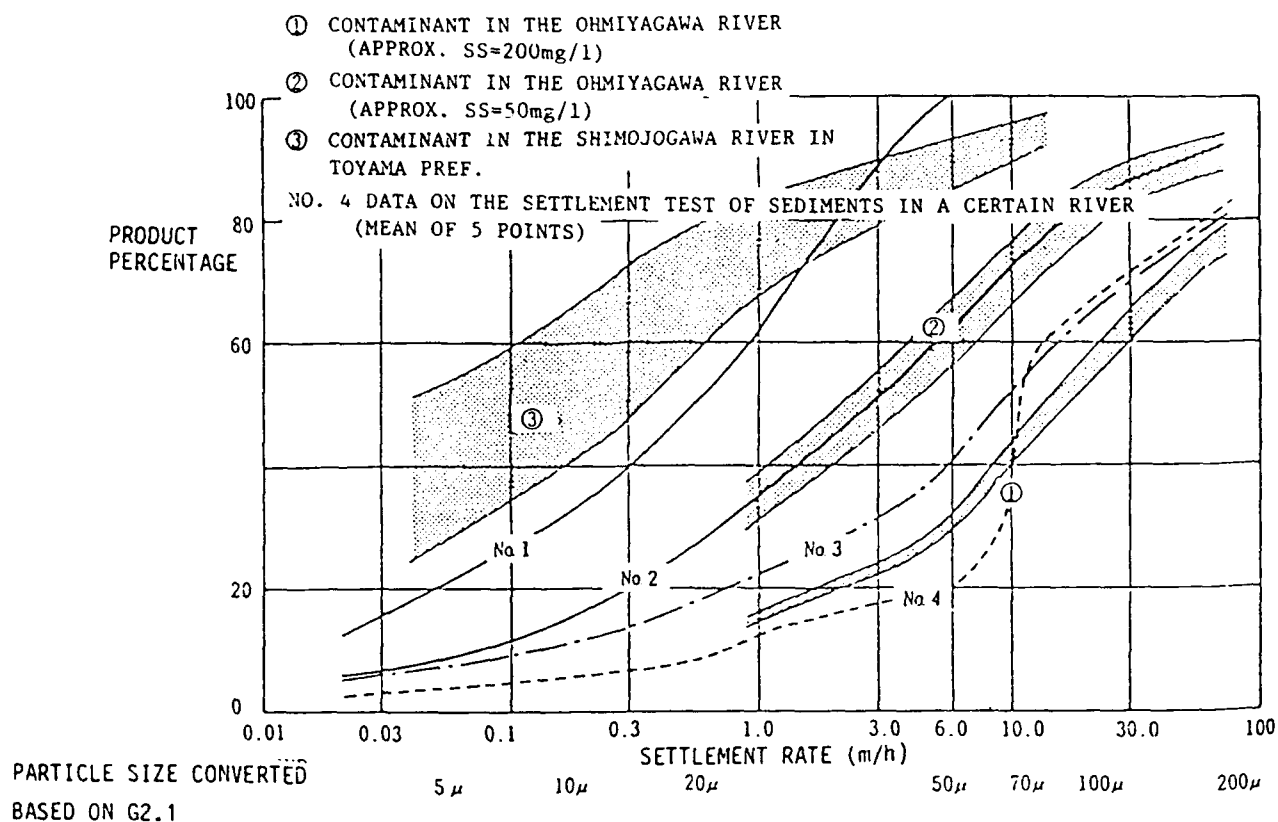


Figure 11. Settlement rate distribution of the flow-in SS load

are generally provided, it is possible to make an estimate with reference to these data.

The accuracy of such an estimation can be further improved, if the data of the above-mentioned annular flume can be obtained.

#### CONCLUSION

The results obtained by the experiment using this bottom mud were approximately similar to those on the sediments of the harbors (Figure 2).

Figure 5 shows the relationship between the composition of the particle size and resuspension of the particles. As clearly seen in these figures, at the rotational frequency of this experiment, along with the decrease in the particle size, resuspension of the particles into the water increased. However, the increase could not be confirmed by experiment because of insufficient performance of the experimental equipment (the rotational frequency).

The speed at which resuspension of the limit in the sediments of the Ohhorigawa River started was calculated from several formulae. As a result, it was found that the flow limit rate,  $U^*$ , was 19 to 46.8 cm/sec, and the average flow rate of the river under this condition was 0.5 m/sec with the maximum flow rate of 1.5 m/sec. Thus, it was concluded that since the flow rate of the Ohhorigawa River in the present experiment was in the range of 0.107 to 0.2 m/sec, it was not fast enough to resuspend its sediments.

Items recommended for study in the future are:

- a. The experimental equipment which can generate resuspension of sediments should be used.
- b. The difference of the relationship with rainfall intensity between the actual place and this experiment should be investigated.

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HOPPER DREDGES APPLIED TO THE  
ALASKA OIL SPILL, MARCH 1989

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ABSTRACT

On March 24, 1989, the oil tanker Exxon Valdez ran aground in Prince William Sound, Alaska. This accident resulted in the largest American oil spill ever and spoiled one of the most pristine areas in North America. In April 1989, the US Army Corps of Engineers was requested to assist in the cleanup of this disastrous oil spill. Two of the Corps' minimum fleet hopper dredges, the *Yaquina* and the *Essayons*, were dispatched to assist in collecting oil. Although unmodified hopper dredges had never been used in this capacity, the *Yaquina* and the *Essayons* proved to be the most effective tools in the recovery of oil. Given proper air support, adequate containment boom, and commitment at the earliest possible time, hopper dredges can make a significant contribution to the cleanup of large oil spills.

BACKGROUND

A cataclysmic earthquake and tidal wave destroyed the port town of Valdez, Alaska, on March 27, 1964. Measuring 8.6 on the Richter scale, it remains the strongest earthquake ever recorded in North America. It created an enormous tidal wave which engulfed Valdez and caused the death of at least 30 villagers. On the 25th anniversary of this tragic event, another flood occurred; only this time the flood was man-made. At 15:04 a.m. on March 24, 1989, the oil tanker Exxon Valdez became impaled on Bligh Reef, hemorrhaging oil into Prince William Sound at an estimated rate of nearly 1,000 gal/sec (3,800 l/sec). Oil escaped from the ship with such force that it rose above the water surface on surging 3-ft waves. Within 4 days, the oil slick covered more than 100 square miles (260 sq km) of Prince William Sound, one of the more pristine areas of North America.



The Exxon Valdez has a capacity in excess of 1.4 million barrels of oil. It is the newest and largest of Exxon's fleet of 19 ships and was delivered in 1986. When the vessel left the Valdez dock at about 9 p.m. on March 23, 1989, bound for Long Beach, California, it was loaded with about 1.2 million barrels of oil. The 987-ft Exxon Valdez was traveling at about 8 knots in the outbound channel when icebergs floating in the area were detected on the ship's radar. The ship's captain requested and was granted permission to use the inbound channel in order to avoid the icebergs. The ship, however, strayed nearly 3 miles (5 km) beyond the eastern edge of the inbound lane. The Exxon Valdez went aground on Bligh Reef about 25 miles (40 km) south of Valdez, Alaska; ruptured 8 of its 13 cargo tanks; and lost an estimated 250,000 barrels of Alaskan crude oil. Thus, the stage was set for America's worst oil spill disaster and the world's tenth largest recorded oil spill ever. The world's largest oil spill occurred 10 years earlier, when nearly 2.2 million barrels of oil from two tankers were spilled near Trinidad.

Alaskan crude oil is pumped from the United States' largest oil reserve. The North Slope oil field is the source of nearly 25 percent of the Nation's oil supply with an estimated yearly market value of more than \$15 billion at current prices. But in order to use the oil, a way had to be found to deliver the oil from above the Arctic Circle to the refineries located in California and in the Gulf and East Coast states. After much consideration, including exhaustive environmental studies, a pipeline was recommended which would link the North Slope oil field to Valdez, Alaska. Valdez is located in an area of Prince William Sound which provides a deepwater port, open year-around. The trans-Alaska pipeline owned by eight major oil companies is a 48-in.-diam, 789-mile (1,270-km)-long tube which carries about 1.5 million barrels of crude oil per day from Prudhoe Bay on the North Slope to Valdez. In 1975, work began on the pipeline which was the largest private construction job in American history. It involved laying and welding together nearly 102,000 sections of 48-in. pipe. The pipe was laid under rivers and caribou migration routes and over mountain ranges. It had to be refrigerated in places to avoid melting its permafrost coating. In other places, it was insulated against wind chill factors of around -100° F (-70° C). Within hours of reaching Valdez, Alaska, the oil is loaded into one of more than 60 tankers that ferry it to refineries on the West Coast or to Panama, where it is pumped through a Panama Canal pipeline into other tankers that ferry it to Gulf and East Coast refineries. By law, none of the oil can be exported. Since the pipeline opened in 1977, an estimated 6.8 billion barrels of oil in more than 8,500 voyages have transited through Prince William Sound without incident. But during the early hours on March 24, 1989, this commendable record came to an end.

Bligh Reef is located toward the northern end of Prince William Sound. Prince William Sound is a 2,500-square mile (6,500-sq km) wilderness that is one of the most pristine and beautiful areas in North America. This remote area contains a maze of inlets, mountains, and fjords and is protected from the storms of the Gulf of Alaska by a series of islands. The Sound includes about 2,700 miles (4,300 km) of shoreline--all wilderness except for a few small villages including Valdez. The entire area supports a human population of only about 10,000. Prince William Sound is home for hundreds of thousands of birds, fish, and mammals, many of which were impacted by the oil spill. The islands of the Sound provide nesting sites for birds such as kittiwake, a gull-like bird, and puffin, a sort of diving duck about the size of a large

grapefruit. The puffin has a distinctive orange and yellow beak. These birds, which depend on the sea for their food source, arrive in the Sound each spring to set up housekeeping on one of many islands that foster more than 100 nesting colonies. The Sound is also used as a resting and feeding area for many species of shore birds, geese, and up to 5 million ducks, as they make their way north to their nesting sites. Prince William Sound also supports the largest number of summering trumpeter swans in the world (about 1,000) and sustains from 5,000 to 14,000 tundra swans. The area is also home to black and brown bears, as well as bald eagles, and is one of the most plentiful fishing grounds in North America. In an average year, the total salmon catch is nearly 20 million pounds. Other fish catches total nearly 30 million pounds, which include a half-million pounds of shellfish. In addition, a \$59 million halibut fishery is based in the Sound. Three species of whales, including the humpback whale, migrate through the area each summer. Resident marine mammals include more than 5,000 sea otters, porpoises, and killer whales. Many of the islands within Prince William Sound are used as haul-out areas where sea lions and harbor seals return each spring to bear their pups.

Crude oil generally has a density of about 0.85. When crude oil is spilled in a saltwater environment, many changes take place. Experience indicates that within the first 3 days, those components that have a boiling point under 200° C volatilize. This change very much reduces the threat of explosion, making the oil relatively safe to collect, handle, and store. It must be remembered, however, that the surface water of Prince William Sound is a cold 3° C in the April-May time period. This temperature has a tendency to slow down the evaporation process. As time goes on, however, the nature of the material changes so as to make it very difficult to handle. About 48 h after the spill, depending on weather conditions and wave action, the oil emulsifies with the seawater to form a very viscous material that contains up to 70 percent water. It was our experience that this material had about the same viscosity as refrigerated chocolate syrup. It was extremely sticky and thus captured anything in contact with it, especially floating debris and vegetation, including kelp. The color of this material turned to a light brown and was referred to by many as "chocolate mousse."

This oily chocolate mousse severely impacted the beaches and shorelines from Prince William Sound to Kodiak Island. It has been estimated that as many as 700 miles (1,130 km) of beach and coastline were impacted by the oil spill. In some cases after high tide, the oily goop left was as much as 6 in. (15 m) thick. As the tides progressed through their normal routine, the oil worked deeper and deeper into the coarse gravel/cobble beaches. It was reported that in some areas, the oil had soaked 4 ft into the beach, in effect sterilizing the beaches of all life.

Many dead birds, otters, and other animals were washed up onto the beaches. These were reportedly scavenged upon by the bears, eagles, and other carnivores, thus impacting these animals also. By mid-April, the oil spill had been blown southwest to the mouth of Cook Inlet and had caused damage to the shoreline of the Katmai National Park on Shelikof Strait, across from Kodiak Island. In so doing, the oil had been blown and carried by the current a total of 500 miles (800 km) in about 3 weeks.

## MOBILIZATION

Both the dredge *Yaquina* and the dredge *Essayons* were outfitted on very short notice. The vessels are designed with the capability to operate for a period up to 30 days independent of any external support. In addition to a 30-day supply fuel and subsistence items for the crew, the vessels were loaded with an oil containment boom, absorbent material, cleaning materials, extra sleeping bags, heating coils, steam hoses, and steam wands. Also, considerable small parts for ship repairs, as well as parts needed to assist in loading and offloading oil, were placed onboard the dredges.

Some equipment necessary to the support of the oil cleanup operation was rented, including an air compressor, 3-in. (7.62-cm) submersible and 3-in. (7.62-cm) diaphragm pumps, and for each dredge a Marco Class I Skimmer. The two types of pumps were placed onboard the dredge *Yaquina* to bring oil onboard the dredge, or to assist in offloading oil from the dredge to a barge or other containment facility. Neither of these pumps was successful due to the viscous nature of the oil. The oil was too viscous to flow toward a normal vacuum draw.

The boom brought from Portland was only 36 in. (0.9 m) in height and proved to be too small to effectively collect oil under wave and wind conditions generated in these Alaskan waters. It is suggested that for future operations, 72- to 84-in. (1.8- to 2.1-m) "sea curtain" booms be purchased and stockpiled.

Charts were furnished to both dredges for the anticipated areas where the dredges would likely work. Due to the tremendous mobilization of equipment to Alaska for the oil spill, it was very difficult to acquire charts locally. Charts additional to those supplied in Portland were subsequently provided by the Coast Guard in Alaska.

In addition to the normal staffing onboard the dredges for dredging operations, the crews were supplemented with two operators for the Marco Class I Skimmer, a radio operator, and a public affairs specialist. The Portland District Safety Officer was initially onboard the dredge *Yaquina*. The primary role of the Safety Officer was to ensure that appropriate tests were conducted to determine the nature of the oil and to prevent any accidents which might result from handling a "volatile" oil. However, as mentioned before, by the time the dredges arrived in Alaska, the danger of explosion from volatiles in the crude oil had passed.

A small survey vessel with crew was placed onboard the dredge *Yaquina* with electronic positioning and fathometer capability. Depending on the area where work is to be performed, it is likely that full hydrosurvey support would not be required, although this capability does exist. An alternative to normal hydrosurveys may be the side scan sonar, as discussed below. However, the vessel did prove effective in assisting with maneuvering the oil containment booms.

A photographer was assigned to the dredge to document the conditions, methods used, successes, and failures so that this information could be provided to others for a technical exchange of information.

Once the dredges arrived in Alaska, additional supplies and equipment were provided, including cots, folding beds, and sleeping bags for personnel assigned both to Exxon and the fishing vessels working in the area. In addition, considerable sorbent, foam pads, cleaning compound, paper coveralls, and gloves were purchased. A 12-in. (30-cm) centrifugal pump with 12-in. (30-cm) suction and discharge hose was delivered to the dredge *Yaquina* while it was in Alaska. This pump was purchased with the intent of providing the dredge capability for offloading oil. Due to the high viscosity and the considerable debris in the oil, this 12-in. (30-cm) centrifugal pump was ineffective. However, it was thought that if the oil could have been heated adequately to reduce the viscosity, this pump would have provided the desired offloading capability.

The dredges required special support for logistics and operations. A team was sent from Portland District to Alaska to supplement the Alaska District Logistics and Operations staffs. Initially, this support consisted of a military officer for onscene coordination between the dredges *Yaquina* and *Essayons* and other vessels and agencies operating in the area, a project manager who coordinated between the Alaska Operations and Portland District Operations sections, and two logistics support personnel.

Transit time for response to an oil spill is dependent both on the dredge and the weather conditions. The dredge *Yaquina* transited from Portland, Oregon, to Prince William Sound at an average speed of 9.5 knots. It departed on 11 April 1989 and arrived at Prince William Sound on 17 April 1989. Because of adverse weather in the Gulf of Alaska, the dredge was forced to travel on the inside passage route, which added approximately 1 day of transit time.

The dredge *Essayons* is more capable of transiting in the face of adverse weather conditions. The dredge departed San Francisco on 13 April 1989 en route to Astoria, Oregon, for outfitting. She departed Astoria, Oregon, on 17 April 1989 and arrived at her assigned station at Port Dick, west of Prince William Sound, on 21 April 1989. She encountered favorable weather conditions and transited at an average speed of 13.5 knots.

#### LOCATING AND COLLECTING OIL

When the dredge *Yaquina* and the dredge *Essayons* arrived, the oil had been exposed to the atmosphere long enough for most of the volatile components of the crude oil to have evaporated. Thus, the dredges were able to take on the crude oil without risk of explosion. Since the Corps dredges are not equipped for pumping inert gases into their holds, it will be again necessary in the future to allow sufficient time for the volatiles to dissipate prior to using the Corps dredges. The time needed is thought to be 24 to 48 hr.

The most efficient use of the dredges was in the recovery of large quantities of floating oil. Locating this oil, however, was a tremendous challenge. Full-time air reconnaissance was important to successful oil recovery. With infrequent air support, it would often occur that oil collection equipment was in one location while the oil was several miles away. By the time the oil collection equipment could be mobilized to the site of the oil, either the oil had moved or very little daylight remained. Recommendations to solve

the problem of both locating oil and getting equipment deployed to the proper location include the following:

- a. Assign sufficient aircraft, preferably helicopters, with deployable flotation markers to each group of oil collection equipment.
- b. Develop a way to locate oil even at night and to project where oil will be so that oil collection equipment can be directed to the appropriate location.
- c. Ensure that the dredges have communications capability to talk with the various aircraft, including military aircraft and fishing vessels operating in the area.

Once the oil is located and equipment mobilized to the site of the oil, skimming operations can begin. A very important component of the skimming process is the oil containment boom.

Initially a 36-in. (0.9-m) boom was used, but it did not prove satisfactory. The most effective oil containment booms were 72- to 84-in. (1.8- to 2.1-m) sea curtains.

A major limitation to using the boom with a dredge was that, in order to be effective, the boom had to be towed very slowly. Maximum towing speed was about 4 knots. At higher towing speeds the apex of the boom would submerge, allowing the captured oil to escape. Also, at higher speeds, the need for maintenance of the booms increased significantly.

Oil was successfully skimmed and collected in several ways. The most common was to have two fishing boats pull an oil containment boom through the water and capture any floating oil and associated debris. The collected oil was so viscous that a bucket dropped onto it would not penetrate through but would stay on top, or a shovel pushed into the oil could not be easily removed. Once the oil had been collected, the boom was pulled into a tight circle. This circle was termed a "donut" and was rather effective in containing the oil until it could be loaded into a hopper dredge or barge. A dredge would pull alongside the "donut" and pump the oil into its hoppers. Often the dredges also deployed a boom attached to the dredge aft of the draghead, which was a second line of defense to prevent the collection oil from escaping. At times the dredge itself in combination with a smaller vessel was used to pull a containment boom. Although it was not tried, there is no reason that containment booms could not be deployed on either side of the dredge in combination with other smaller vessels. In this way, the effective swath of oil collected by the dredge could be doubled. Also, at times, "donuts" of oil collected by fishing vessels were opened up directly in front of the dredge's boom for the dredge to recollect. This method proved to be quite effective because it increased the continuity of the overall operation.

#### LOADING OIL

Onloading of oil into the hoppers was very successfully accomplished by using equipment already installed on the dredge. No extensive structural modifications were required.

The position of the dragheads on both the dredge *Essayons* and the dredge *Yaquina* were changed by rotating the dragheads 180 deg. Under normal operations, the draghead is lowered into the water and pulled across the bottom, sucking material up the dragpipe into the hopper much the same way as a household vacuum cleaner operates. Initially, the draghead was left in the dredging position and lowered into the collected oil. With the draghead in this position, the dredge was ineffective in loading the oil into the hopper. If the draghead was lowered too far into the water, only seawater was pumped; but as the draghead was raised into the oil, the pump would lose prime. An efficient elevation or position of the draghead could not be found, partly because of the constant vertical movement of the dredge. As an alternative, the draghead was removed, rotated 180 deg, and reattached to the dragarm. The draghead was then placed below the surface, underneath the "donuts" of oil. This placement provided a huge suction mouth which allowed the oil to be sucked through the dragpipe into the hoppers very quickly.

The pumping rate for the dredge *Yaquina* was approximately 100 barrels per minute which included the oil, vegetation and other debris, and some seawater. The pumping rate for the dredge *Essayons* was about 350 barrels per minute. The capacity for storage of oil onboard the dredge *Yaquina* is approximately 4,000 barrels, which compares to approximately 29,000 barrels on the dredge *Essayons*.

During the loading operation with the draghead inverted, a critical factor was maintaining a suitable depth of the draghead beneath the water surface. The optimum depth was a function of the flow characteristics of the oil and horsepower of the pumps. It was critical that the proper height for the draghead be maintained so that the maximum possible percent oil could be unloaded. If the draghead was located too far beneath the surface of the oil, the percent of oil was quite low. If the draghead was too high, the pump would lose prime.

It was apparent that significant improvements could be made in the design of the draghead for oil recovery. The only modification to the dragheads used in the Alaska oil spill recovery was the construction of a cage around the draghead to help prevent the oil boom and debris from being sucked into the draghead. Furthermore, the suction head required for oil spill recovery could be significantly different from the present design of the draghead. The following improvements should be directed toward helping increase the percent of oil brought onto the vessel.

- a. Capability of minimizing water intake while maximizing the surface area.
- b. Smooth features.
- c. A cage to prevent oil boom and debris from being drawn into the dragarm.
- d. A circular head which would allow drawing material from 360 deg.
- e. An easily removable cleanout grate.

Because some water is introduced during the unloading process, it was necessary to decant the oil brought into the hopper. The oil separated rapidly from the water, rising to the surface as it was lighter than seawater. Decanting was accomplished by opening one of the hopper doors 2 to 3 in. The water was thus slowly released until the desired oil level was reached; then the doors were closed. Because of the debris present with the oil, there was a problem with debris getting lodged in the door openings and preventing a tight closure. Thus, it is recommended that before collecting oil, a screen be fitted above each of the hopper door openings to remove any large debris that would prevent the doors from closing.

#### OFFLOADING OIL

The three most limiting factors that affected efficiency in the collection and disposal of oil were the weather, difficulty in locating large quantities of floating oil, and difficulty in disposing of the oil once collected in the dredges' hoppers. With no possible control over the weather, it was often difficult to effectively locate and collect oil. It was during these times and during darkness that collected oil was offloaded from the dredge *Yaquina* to oil barges.

Once oil was successfully loaded into the dredge hopper, the problem became how to offload it to a barge. Barges were provided to receive the oil that had been collected. Because of the viscosity of the oil, which increased the length of time it remained on the vessel, it was nearly impossible to offload using conventional pumps. During the operation, many different pumps were tried, all with limited success. The most successful pump was a "Supervac," but its operation was painfully slow. The Supervac is a truck-mounted vacuum system that is typically used to empty sewage tanks or similar containments. It is essentially an air vacuum pump which has a long vacuum line that can be moved to the oil surface. One of the problems was that the oil was so viscous that suction simply created a hole in the oil and it would not flow to fill the hole. Therefore, the vacuum line had to be moved from point to point within the hopper, which was a very labor-intensive and physically demanding task. One of the limiting factors of using the Supervac was that the truck would fill quickly and then would have to be discharged. This process was lengthy because the truck was designed to discharge through a 6-in. (15-cm) hose. The crew of the dredge *Yaquina* improved this discharge rate by constructing a large rectangular box around the hatch of the barge. Thus, the truck could open its back like a dump truck and discharge the oil directly into the rectangular box. This idea was subsequently utilized by contractors on other operations.

In an attempt to speed the offloading process, other options were also tried. On the dredge *Yaquina*, a 12-in. (30-cm) centrifugal pump was installed. The suction line was attached to the hopper using a special flange around a 12-in. (30-cm)-diam hole cut through the hopper bin wall. The flange was located approximately 6 ft below the hopper bin deck level. During the test, water was added to the hopper to keep the height of the oil at the discharge pipe level. Various heights were used, and the discharge valve was adjusted to increase the vacuum. Four crew members with poles and large knives on poles removed wood and assisted in breaking up the viscous oil. In addition, a fire hose was used to create a slurry. At the time of the test, the collected oil was approximately 4 ft thick. Although large quantities of

water were pumped, a very small amount of the product was discharged, because the oil would not flow to or into the discharge pipe, even with crew members assisting. Because the oil was so viscous, the water below was pulled through the oil and discharged. In addition, the impeller of the pump became heavily plugged.

Another pump that was somewhat successful was the "Vac-u-vator." It acted in a manner similar to the Supervac in that it was an air vacuum pump.

As explained above, the challenge of how to offload the oil was never satisfactorily resolved, since it had an opportunity to decant and further thicken to a point where it would hardly flow. This problem was compounded by the intrusion of vegetation, wood debris, and other material that made the mixture seem more like a sticky conglomerate than anything resembling crude oil (which is relatively easy to transport by centrifugal pumps or several other means). It will be necessary to fully research this challenge to ensure that an effective offloading method is developed prior to engaging dredges again on this type of operation.

One alternative that seems to show promise is to preheat the oil mixture immediately before it enters a centrifugal pump. It is recommended that some sort of heating system be developed that is steam driven. Electrical heaters may pose potential safety hazards when generating temperatures in the range required to liquefy the oil. There are several ways to implement such a system. The simplest might be to install a "Donkey Boiler" with the associated steam coils and lines. Another is to build steam pipes in the hopper or have them available as a quick add-on feature. One possibility would be to upgrade the vessel's steam plant or to install an auxiliary plant.

Other methods such as augers or conveyers should also be given consideration during this much-needed research. Another alternative which would totally eliminate the need to offload would be simply discharge the oil directly into a barge and not use the dredge hopper as an intermediate storage area. It would be easy enough to either tow such a barge or have it pushed by a tug. The challenge of how to decant the oil within the barge, however, would have to be first resolved. On the surface, the task would seem to be relatively easy in that the barge could be outfitted with pumps to remove the water from near the bottom of the barge.

#### OTHER DREDGE USES

Once deployed to an oil spill recovery operation, the best use for a dredge would normally be to collect and dispose of floating oil. In our experience in Alaska, however, the dredges were found to be able to act in other capacities which increased the efficiency of the overall cleanup operations. The spill response emphasized the capability of a dredge not only to handle large volumes of oil-laden liquids, but to act as a self-contained command and control vessel with full communications capabilities and thus as a mother ship to fleets of smaller vessels (by supplying fuel, water, and other supplies). Because of a dredge's ability to pump large volumes of water, consideration was given to using a dredge as a pump station to provide water to shore to flush the oil from the beaches. While a dredge could be used in this manner, it was shown that such a deployment would be relatively inefficient because barge-mounted pumps could achieve the same result at considerably less cost.

Also, in the final analysis, simply using water in an attempt to flush oil from a beach is a futile effort and does little good once the initial layer of oil debris has been removed.

## CLEANUP

Cleanup of the vessels proved to be a formidable task. The dredge *Yaquina* arrived in Seward, Alaska, for cleanup on 26 May 1989 and departed on 8 June 1989. Cleanup of the dredge was accomplished first by offloading the remaining oil using Supervac. Then, a tremendous amount of labor was provided by local contractors to thoroughly clean the vessel. Because of the viscous nature of the oil, this task required a combination of steam with detergent and hand labor to wipe down nearly all surfaces on the dredge.

The dredge *Essayons* arrived in Seward, Alaska, for cleanup on 1 June 1989. She departed Seward 47 days later on 18 July 1989. Cleanup of the dredge involved the same initial offloading procedures for oil in the hopper. In addition, however, it required intensive manpower operations for offloading the 180 cu yd (125 cu m) of oil-contaminated sand, gravel, and kelp. One of the most costly lessons learned during this operation was the result of placing sand, gravel, and other oil-contaminated material into the hopper of the dredge. The emulsified oil, sand, and gravel mixture turned into asphaltic concrete and had to be hand-chipped and sandblasted from the hoppers. This material was unloaded during operations at Katmai National Monument. The rotting organic material resulted in a highly obnoxious odor which required respirators for those working in the hopper area. Also, there was the problem of sealing the hopper doors. These doors are not designed to be watertight, and water continued to leak, hampering efforts to clean the lower portion of the hopper. This problem was finally resolved by using divers to seal the doors from below. The water in the hopper could then be pumped out and the remaining material removed. Because of the challenges which this operation provided, cleanup of the dredge dragged on. Although the dredge *Essayons* is a much larger vessel than the dredge *Yaquina*, it is felt that cleanup of the dredge *Essayons* could have been handled in a time frame comparable to that of the dredge *Yaquina* if oil-contaminated sand, gravel, and vegetation had not been placed in the hoppers.

The dredge *Yaquina* returned to its home base in Portland, Oregon, on 15 June 1989. The dredge *Essayons* arrived on 21 July 1989.

## RECOMMENDATIONS AND LESSONS LEARNED

### Preparedness

It is clear to everyone that worked on the oil spill that a timely response is absolutely critical. This absolute need for an immediate response is a compelling reason to have a standby capability to collect and remove large quantities of spilled oil in a short amount of time. Even if those responsible had been able to totally boom off the area in the immediate vicinity of Bligh Reef, it is doubtful that the boom could have maintained its integrity during the wind storm of 26 March 1989. Those 60-knot (110-km/hr) winds would have most likely destroyed any attempt to corral and contain a spill of this magnitude. It is imperative that a system be devised to allow

for quick recovery of oil from the water. Any spill that takes place in open water will be extremely difficult to contain for a sustained period of time.

Dredges are deployed around the world and are concentrated near areas of high industrialization, i.e., areas of high risk for some kind of oil spill disaster. Because of their mobility and intrinsic ability to pump large quantities of oil, dredges could easily be used to complement the oil industry's own resources in fighting large oil spills.

### Methodology

During an oil spill recovery operation it is important that a dredge be primarily used for its highest and best use which, in our opinion, is to remove oil from the water surface. In Alaska, much of the vessel's time was spent mobilizing from one hot spot to the next. During this travel time the dredge was unproductive. In an effort to increase productivity, a floating boom was attached to the dredge so that oil could be collected as the dredge moved from position to position. The boom, however, reduced our speed to less than 4 knots. Greater speeds caused the boom to submerge and lose part or all of the collected oil. Thus, a dredge should work with a series of smaller collector vessels. In this way, the dredge could spend most of its time recovering oil and leave the job of collecting oil to smaller, less costly vessels. A type of flotilla was envisioned under the command and supervision of a Flotilla Manager, located aboard the dredge. A hopper dredge would be the hub of the flotilla responsible for gathering, collecting, and disposing of all floating oil within a distinct geographical area. Each flotilla would consist of a dredge, recovery and collector booms, the necessary vessels to tow the booms, reconnaissance aircraft, and other miscellaneous equipment to support the oil recovery effort. A geographic area of responsibility would be assigned to each flotilla. Within this area, floating oil would be gathered by small collector booms, transferred to larger storage booms, and then pumped into a hopper dredge for final disposition to an oil barge. It is expected that each flotilla would be generally self-sufficient and thus require little support from other sources. Air support to locate recoverable oil and communications to coordinate activities are absolutely essential ingredients to the flotilla.

A typical operation for such a flotilla would include the following considerations:

- a. Each flotilla would be assigned and responsible for a specific geographical area. The size of the area would be dependent on many factors, including:
  - (1) Type and length of coastline.
  - (2) Quantity and extent of oil.
  - (3) Weather conditions.
  - (4) Resources available (such as amount of boom).
- b. The area would be further subdivided. Two vessels with collector booms would be assigned to work in the smaller areas in and out of

bays and close to shorelines. It is therefore essential that these units be relatively small and maneuverable.

- c. Storage units with larger towing vessels would service up to 10 collector units and would transit between locations to pick up oil from them as well as collect oil themselves in the open water.
- d. The dredge would sail between storage booms, pump out the oil, and then move to the next storage unit location. A large oil barge with a pump would be moored within the area to allow offloading of the dredge when it reaches capacity or during night hours when skimming becomes inefficient.

The dredge would be offloaded regularly, prior to such time the oil could "gel."

Solids from beach cleanup should be loaded directly onto barges, rather than into the dredge hopper. Barges are much less costly and can maneuver closer to the beach.

Where possible, a conveyor belt system for loading solids from the beach cleanup to a barge is suggested. Bags of debris could be broken directly onto the conveyor for direct loading onto the barge.

#### Communications

There is a definite need for satellite communications, which would include a FAX machine onboard both dredges. This equipment would enhance the ability to act as a command and control vessel. It would also enhance administrative matters, such as submission of reports, requisitions for supply, and public affairs releases to the media.

Another communication concern is the availability of handheld radios for both the crew on the dredges and the crew on the fishing vessels. Such handheld radios should be designed for rugged ocean environment conditions.

Reporting requirements for production during oil cleanup operations are very demanding. Because of the nature of oil cleanup operations, it must be pointed out that both hopper measurement and barrel count is judgmental at best. The oil and water mixture which is loaded into the hoppers initially separates fairly quickly. However, it does not totally separate. There are still pockets of water in the oil. In addition, neither the viscosity of the oil nor the thickness of the oil on the surface of the water is uniform. Over time, water and oil do continue to separate. Thus, the oil in the hopper does become more dense and thus smaller in volume. Because of the changing nature of the oil, it is important that all agree on how the information should best be gathered and understand that volumes reported are only estimates.

#### Equipment

The 72- to 84-in. (1.8- to 2.1-m) sea curtain oil boom proved to be very effective. There was, however, a severe lack of this type of boom. It is recommended that each of the dredges used for oil recovery have available a

complete kit of this boom of approximately 1,000 ft (300 m). The kit should include storage drum and repair parts.

It is also recommended that net reels on fishing vessels should be investigated to determine if they could be adapted for boom deployment and retrieval. Storage of the boom on the reels would be ideal.

Since this cleanup was the first time that the dredges had been deployed in conjunction with oil booms, there were no adequate tie-off points. It is recommended that a bracing system be constructed that would allow the bridle rope either to be tied off near the water line or to go through a fair lead and be tied off on deck.

A continuing problem when loading oil from the donuts was that the oil boom would tend to be sucked into the draghead and often damaged. As a result, a conical cage was made of steel bars for the dredge *Essayons*. The tops of all the bars should come together about 3 ft above the draghead. It is recommended that round stock or heavy pipe be used as opposed to flat or angle stock. This cage would also prevent large debris from clogging the draghead and forcing a shutdown. In addition, to address the problem of debris, it is advisable to have 20-ft (6-m) pike poles onboard for use in clearing the debris from the vicinity of the draghead. The sharp point on a typical pike pole should be rounded because otherwise it can easily cause damage to an inflatable boom.

There is a clear need for a small boat with an outboard motor, such as a Zodiac. A small skiff was useful for assisting in oil boom deployment and also allowed the crew to go to shore to transfer people and equipment. During oil recovery operations in Alaska, helicopters frequently brought people and equipment onto remote beaches. Without such a small vessel, transportation from the beaches to the dredges would be very difficult.

It was apparent that there was a need for additional information on depths and locations of hazards to navigation. The shoreline in Alaska is extremely hazardous and has many uncharted areas. Use of a side scan sonar should be investigated to determine if such equipment could detect hazards before they become a problem to the ship.

During the cleanout of the dredge *Essayons* in Seward, it became apparent that inability to completely seal the hopper doors was a problem. Although not a problem during normal dredging operations, it became very difficult to remove all contaminated debris from the hoppers because of water leakage through the hopper door deals. It is therefore recommended that an inflatable tube the length of the hopper doors be developed that would allow quick sealing when necessary.

The following recommendations for equipment could apply equally to both the dredge *Yaquina* and the dredge *Essayons*. Other pieces of equipment which should be placed onboard a dredge prior to deployment for an oil cleanup operation include:

- a. A Coast Guard-approved gasoline storage area aboard the dredge for gasoline storage. The gasoline would be used to resupply skimmers and small craft outboard engines.

- b. A sonic ullage gauge for accurate sounding of oil. This device could be similar to systems used on tankers with an additional sonic gauge to determine the actual oil/water layer in the hopper.
- c. Cages around the screws of the workboats to protect the screws from debris in the water and rocks when going ashore for passenger pickup.

#### CONCLUSION

Based on their excellent performance in the Alaska oil spill cleanup, the hopper dredges have a very useful role in any future large oil spill recovery efforts. Provided with the proper air support and equipment, and provided they are deployed at the earliest possible time, hopper dredges remain a strong, effective option for meeting oil spill cleanup requirements.

#### ACKNOWLEDGMENTS

The authors would like to acknowledge the crews of both the dredge *Yaquina* and the dredge *Essayons* for their assistance in preparing this paper as well as their extraordinary efforts in dealing with the oil spill. It was only through these efforts that a workable plan was found that proved the effectiveness of dredges in oil spill recovery operations. We would especially like to acknowledge the following for their written comments on this paper:

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INFLUENCE OF ANOXIC WATER IN TOKYO BAY AND ITS  
MANAGEMENT PLANNING

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ABSTRACT

Recently, upwelling of anoxic water, called "Aoshio," has been frequently found in the inner part of Tokyo Bay. As the occurrence of Aoshio causes shellfish to perish, the study of Aoshio is very important to maintain the natural environment.

In this paper, the analysis of Aoshio on basis of past data and field studies in 1987 is presented with a simulation model for Aoshio occurrence.

Principal results are as follows:

- a. The occurrences of Aoshio are most frequently found from July to September and near the coast of Funabashi.
- b. The mechanism of Aoshio occurrences is mainly due to coastal upwelling effect of anoxic water mass near bottom through northern wind duration in summer.
- c. Simulation model studies for Aoshio have modeled the actual phenomenon in the field, such as in 1987.
- d. Dredging and capping are the most effective ways to diminish Aoshio occurrence.

INTRODUCTION

The water quality in Tokyo Bay has remained on the same level since 1975 under chemical oxygen demand (COD). Although when considering values of COD it is seen that the water quality is not contaminated, the water in Tokyo Bay actually reaches high eutrophication in another viewpoint such as frequencies of red tide in summer.



Recently, the so-called Aoshio occurs frequently in summer along the coast from Urayasu to Chiba. Aoshio may be the phenomenon by which the anoxic water mass near bottom is upwelled. This phenomenon causes severe damage to the fishery and sometimes kills shellfish.

As one part of several studies to improve water quality, studies for the management plan of Aoshio have been carried out in the interior of Tokyo Bay from 1986 to 1988 under the Second District Port Construction Bureau, Ministry of Transport.

In 1986, the data about red tide and Aoshio were collected and synthesized. In 1987, the field observations were performed. In these studies, efforts were made to elucidate the actual cause of Aoshio and the mechanism for its occurrence.

Besides, in 1988, the simulation model for an Aoshio occurrence was constructed, and the accuracy of this model and the management plan for protection of Aoshio were discussed.

#### OCCURRENCE OF AOSHIO

Aoshio corresponds to the phenomenon which shows widely blue and white color on the sea surface for several days. The expression, Aoshio, is simply a popular name and is not defined quantitatively.

The color of seawater in the inner parts of Tokyo Bay is usually yellow green or brown in summer, but at the occurrence of Aoshio it changes to blue white or blue green. In general, these changes of color help locate the occurrence of Aoshio. At the same time the transparency of seawater increases to at least 1 meter and is often several meters higher than it is in the ordinary water without Aoshio. Other characteristics of Aoshio water are that the temperature and oxygen are lower, and the salinity is higher than offshore.

According to past data, Aoshio was first found in 1951, but from 1965 to the 1970's it occurred very often. In fact, occurrences of Aoshio tended to be found more frequently in the 1970's.

Considering seasonal variations of Aoshio, it seems to occur generally from May to September, especially from July to September. The sites of Aoshio are concentrated near the coast of Funabashi, as discussed later. The occurrence of Aoshio in the past was described by Kataoka, Fuse, and Komatsu (1988).

#### MECHANISM OF AOSHIO OCCURRENCE

From the studies carried out on the basis of past data in 1986, the mechanism of Aoshio occurrence was supposed to be as follows.

Considering the trend of oceanographical conditions of Tokyo Bay in summer, vertical distributions of water temperature have remarkable thermocline, and surface salinity is very low due to discharge of fresh water.

According to these factors, the water mass in Tokyo Bay indicates remarkable stratified structure in summer, and then vertical convection of water

is naturally controlled. Accompanying the lowering of vertical convection, the anoxic water mass may be formed near bottom, especially in the inner part of Tokyo Bay. If the northern wind blows continuously there, the surface water near the coast moves offshore, and the compensation for this water will be done by the bottom water near coast in the interior of Tokyo Bay. Thus, the appearance of the anoxic water mass near the surface generates the Aoshio (Figure 1). As noted, the cause of the characteristic blue-white color of Aoshio is due to the formation of sulphur by the contacts between the sulphuric ion of the anoxic water mass and dissolved oxygen near the surface (Samukawa et al. 1987).

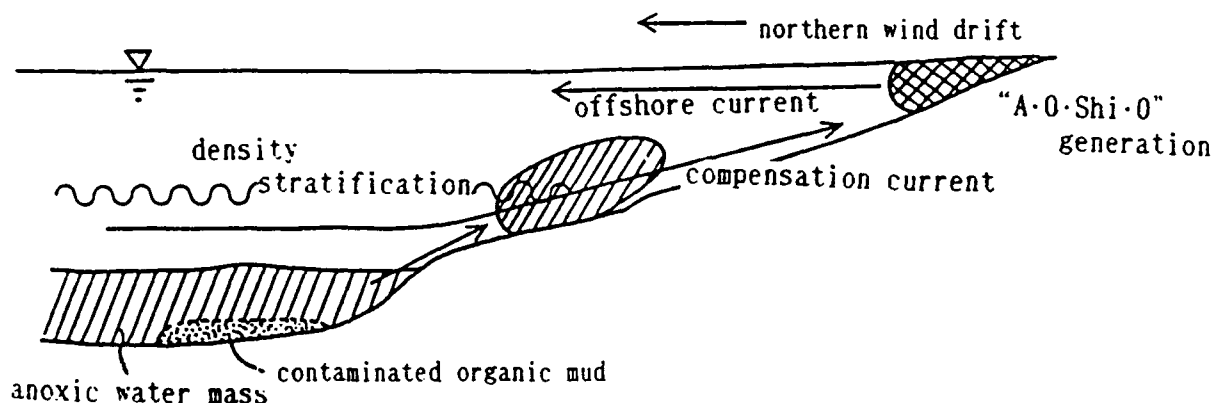


Figure 1. Supposed schematic map for mechanism of Aoshio occurrence

#### FIELD STUDIES OF AOSHIO

##### Process of Research

In 1986, it was presumed that Aoshio should have occurred from coastal upwelling of the anoxic water mass formed under stratified density structure conditions and in a period of continuous blows of the northern wind in summer. Another factor to consider is the effect of gentle slope in bottom topography.

Thus, in 1987 in order to investigate this effect of bottom topography, the field studies were carried out for limited sites of frequent Aoshio occurrences.

Figure 2 and Table 1 show conditions of the Aoshio occurrence and the area of Aoshio on the basis of field operation in 1987, respectively. The observations were performed concentrating on 18 days from August 11 to September 15 because August and September are recognized to be the frequent period for Aoshio occurrences.

Aoshio occurrences were observed for 10 of the 18 days (Table 1). The study area was restricted offshore of Funabashi channel because of information from past data. In this area, Aoshio occurrences were frequent between the area north of Funabashi channel and the shoreline from Funabashi to Makuhari (Figure 2).

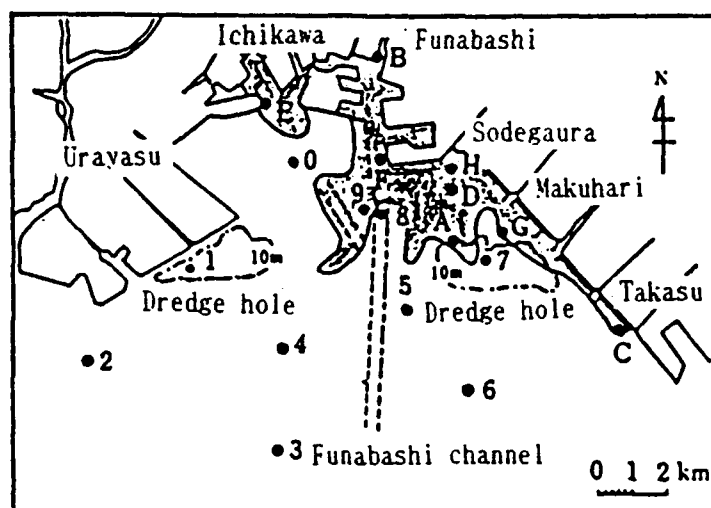


Figure 2. General map of area where Aoshio occurred (shown in shadow)

TABLE 1. AOSHIO OCCURRENCE IN THE INNER PART OF TOKYO BAY\*

Date and Time	Site of Aoshio Occurrence	Area ha
Aug. 25 (13:00-12:00)	Mooring station of Funabashi	22
Aug. 26 (9:10-12:30)	North of Ichikawa channel	29
Aug. 27 (approx. 15:00)	North of Funabashi channel	122
Sep. 2 (12:50-16:20)	Offshore Takasu	11
Sep. 4 (9:30-10:30)	Offshore Sodegaura and south of Ichikawa channel	44 114
(12:50-17:00)	Offshore Sodegaura	25
	Along Ichikawa channel	64
	South of Ichikawa channel	58
	Offshore Makuhari	47
Sep. 5 (9:10-13:00)	North of Funabashi channel	158
Sep. 6 (8:20-11:20)	North of Ichikawa channel and interior	164
Sep. 12 (8:50-13:10)	North of Funabashi channel and mooring station	110
(13:30-16:30)	Offshore Makuhari	223
Sep. 13 (7:50-12:10)	Mooring station of Funabashi	110
(13:10-16:30)	Mooring station of Funabashi and offshore Makuhari	83 115
Sep. 14 (8:40-12:10)	Mooring station of Funabashi and offshore Makuhari	153 243
(13:00-17:00)	Mooring station of Funabashi	170

\* Period of observation: August 11-September 14, 1987.

The Aoshio scales, with regard to duration and area, were considerably large during the periods September 4-6 and September 12-14. With the exception of the above-mentioned Aoshio in 1987, other Aoshio occurrences were reported on June 29 (near Ichikawa channel), July 22 (near Ichikawa channel), and August 2 (at Chiba port and near Funabashi channel) (Chiba Prefectural Fisheries Experimental Station 1987).

#### Wind Conditions at Aoshio Occurrence

Since it is said that Aoshio appears depending on the northern wind duration in summer, observation results of wind on the sea surface were analyzed in summer 1981 to verify the relationship between Aoshio and wind (Figure 3).

The continuous blows of northern wind were found from August 25 to 26, on September 2, from September 4 to 6, and from September 12 to 14 or on the preceding day of these intervals. These periods correspond to the occurrence of Aoshio (Figure 3).

Although the same northern wind durations were found on August 11 and 18, Aoshio did not occur. Since according to oceanographical data in the inner part of Tokyo Bay the anoxic water masses had not been found on the days previously mentioned, the possibility of an Aoshio occurrence was very low.

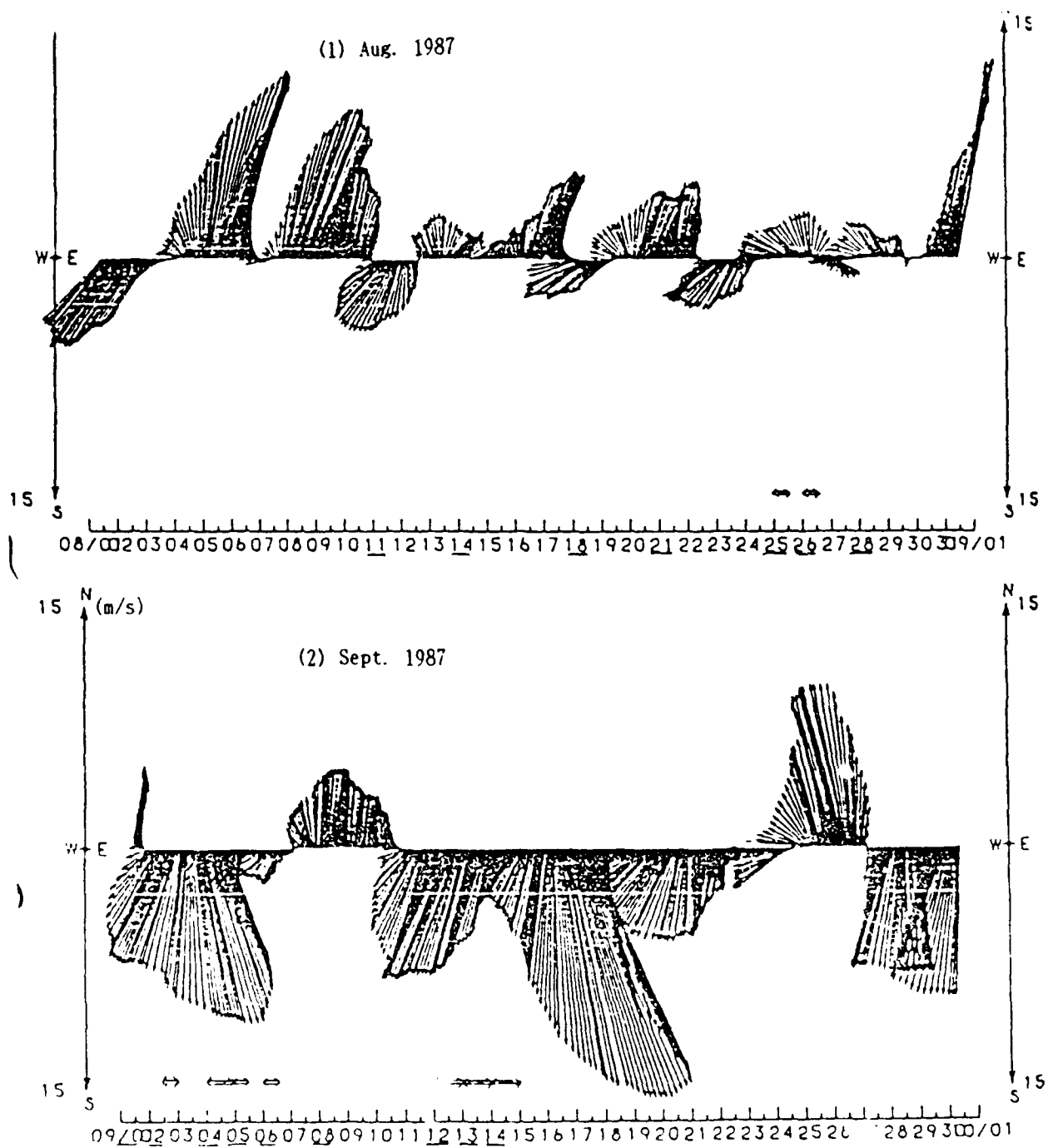
From Figure 3, the north and northwest winds were dominant from September 4 to 6, and the north and northeast winds were dominant from September 12 to 14. The former brought Aoshio west of Funabashi channel, and the latter east of it, respectively. Thus, the correlation between the site of Aoshio and the wind direction indicates that the wind might induce Aoshio.

#### Oceanographical Conditions at Aoshio

The time series of vertical distributions of water temperature, salinity, and oxygen are shown for station 9 north to Funabashi channel in Figure 4. (See Figure 2 for locations of these sites.)

The reason that Aoshio did not occur on August 11 and 18 when northern winds were blowing on both days might be dependent on oceanographical structure. Namely, the temperature and salinity were almost same from surface to bottom. Besides, values of dissolved oxygen (DO) were indicated above 4 mg/l through all depths. Since salinity in all layers was 28 to 30 ppt on August 11, 14, and 18, salinity values near the bottom were lower than normal conditions. From these data, it is supposed that the anoxic water masses disappeared or were removed offshore by a strong vertical disturbance due to duration of southern wind from August 4 to 10 (Figure 3). The same phenomena with uniform temperature and low salinity at all depths were found on August 28 and September 1, 8, and 12. On the other hand, water temperatures in all layers were low but the salinity near the bottom was high, namely, above 32 ppt; the values of oxygen were below 4 mg/l at the Aoshio occurrence from September 4 to 6 and from September 12 to 14.

Water qualities were compared before and during the Aoshio occurrence. During the Aoshio occurrence water temperature and oxygen were lower, and salinity was higher on the surface and near bottom than before the occurrence (Kataoka, Fuse, and Komatsu 1988).



Note: 1. Underlined dates are observation days.  
2. Arrows show hoshio occurrence.

Figure 3. Continual wind vectors for 24 hr at Keiyo Sea-Berth

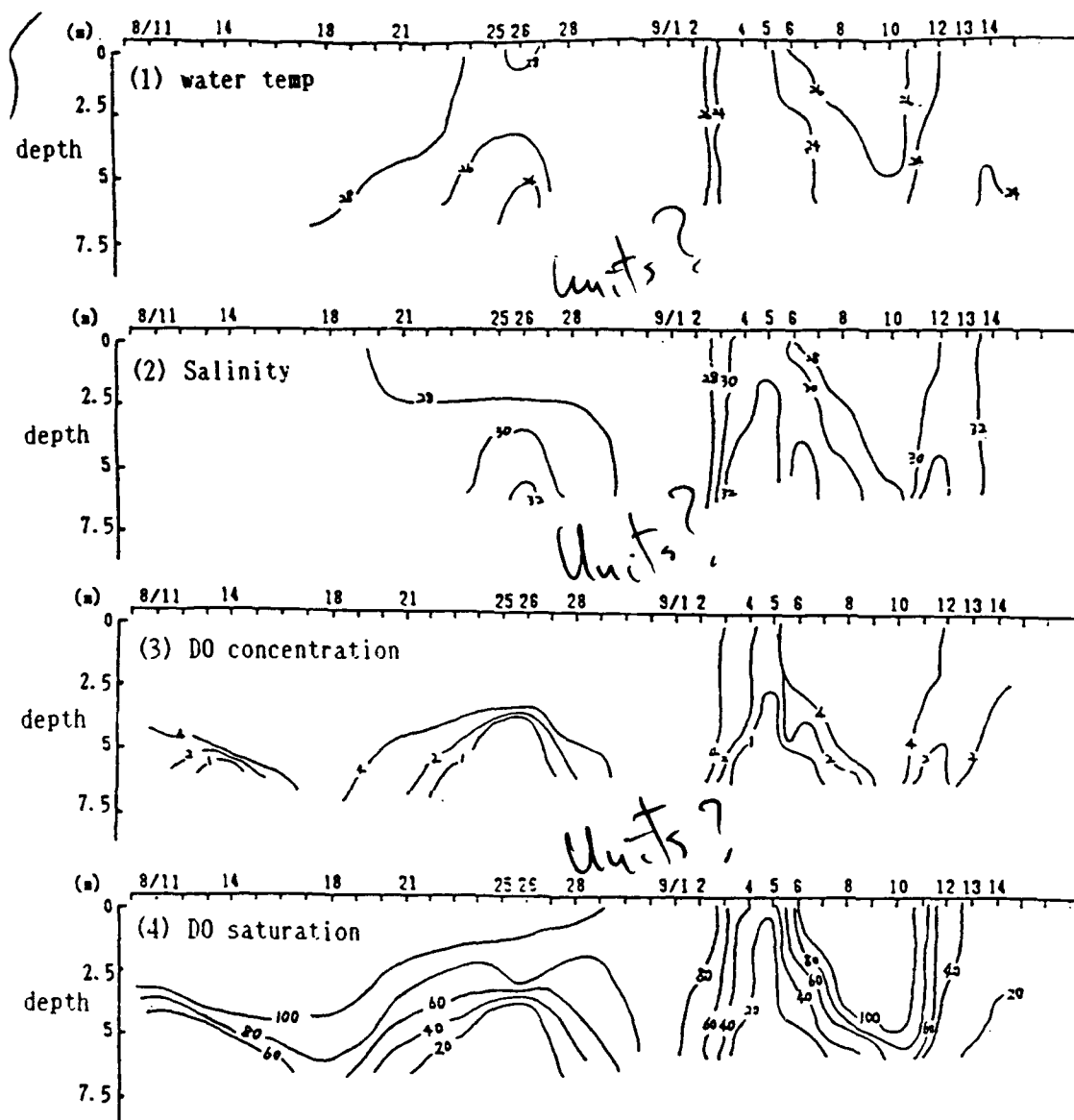


Figure 4. Time series of vertical distributions of water temperature, salinity, and dissolved oxygen (August 11 to September 14, 1987)

#### Distributions of Anoxic Water Mass

In summer when stratified layers develop, DO values in the bottom tend to be low in all interior locations of Tokyo Bay (Tokyo Metropolis, Chiba and Kanagawa Prefectures 1988). Thus, if the coastal upwelling originated by the northern wind occurs, it is possible to cause an Aoshio to occur anywhere in the inner part of Tokyo Bay.

Another supposition about an Aoshio occurrence that should be considered is its relation to bottom topography. The dredge holes remain in several places after the reclamation work. It is supposed that these holes fulfill

the stagnant role for water movement. In order to assess whether these dredge holes have an important function for anoxic water mass formation near bottom, DO values were measured near bottom (1 meter above the bottom) in the inner part of Tokyo Bay in 1987. The appearances of anoxic water (below 2 mg/l) are shown in Figure 5. In this figure the frequencies of anoxic water were given by numerals that appeared among all observations. Although anoxic water masses were found in all observations of the dredge hole, they were also found in about 75% of the non-dredge hole areas. According to these data, the principal cause of an Aoshio occurrence in the inner part of Tokyo Bay should not be due to the local topographic effect such as the dredge hole but should depend upon results showing wide distribution of anoxic water by meteorological and oceanographical conditions.

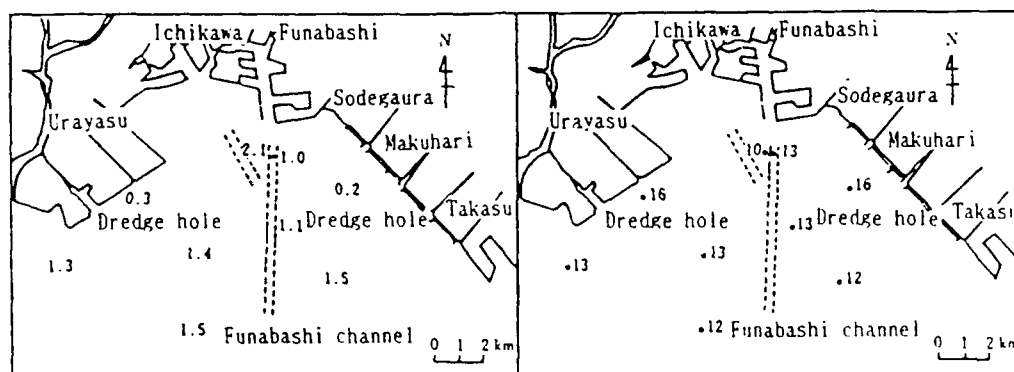


Figure 5. Conditions of appearance of anoxic water mass (August 11 to September 14, 1987)

#### FORECASTING MODEL FOR AOSHIO

##### Fundamental Consideration of This Model

The occurrence process of Aoshio in Tokyo Bay is summarized as two processes:

- a. Formation of anoxic water mass near bottom in the stratified period (biological and chemical process).
- b. Upwelling of anoxic water mass accompanying the duration of the northern wind (physical process).

To construct the forecasting model for an Aoshio occurrence, it is necessary to express exactly what is demanded of both processes in the model. In the biological and chemical process, it needs to express the consumptions of oxygen near bottom through phytoplankton production and its decomposition of bottom mud. In the physical process, it is necessary to indicate the physical structure of the coastal upwelling about the anoxic water mass near bottom through wind drift on the surface.

Since the duration of Aoshio is for 2 or 3 days (maximum) and the states of anoxic water are continued even near the surface, it must be considered to consume oxygen by the oxidation of sulphuric substances in anoxic water

(Samukawa et al. 1987). By these examinations it is suggested that the behavior of sulphuric substances is a very important factor in the construction of the model of Aoshio.

When modeling the two previously discussed processes, it is important to fulfill the following conditions:

- a. Expression of nutrient cycle structure within the low trophic level.
- b. Expression of processes of sulphide behavior and oxygen consumption.
- c. Expression of wind drift current and density current.
- d. Expression of three-dimensional model which is capable of indicating the behavior of the anoxic water mass near bottom.

In this study, a four-layer model is used as transport movement phenomena including wind drift current and density current; the model of nutrient cycle is shown by links of trophic chain in the low trophic level.

These processes in both models can conveniently be calculated in two steps:

Step 1: Forecast the formation of an anoxic water mass  
(transport movement without wind).

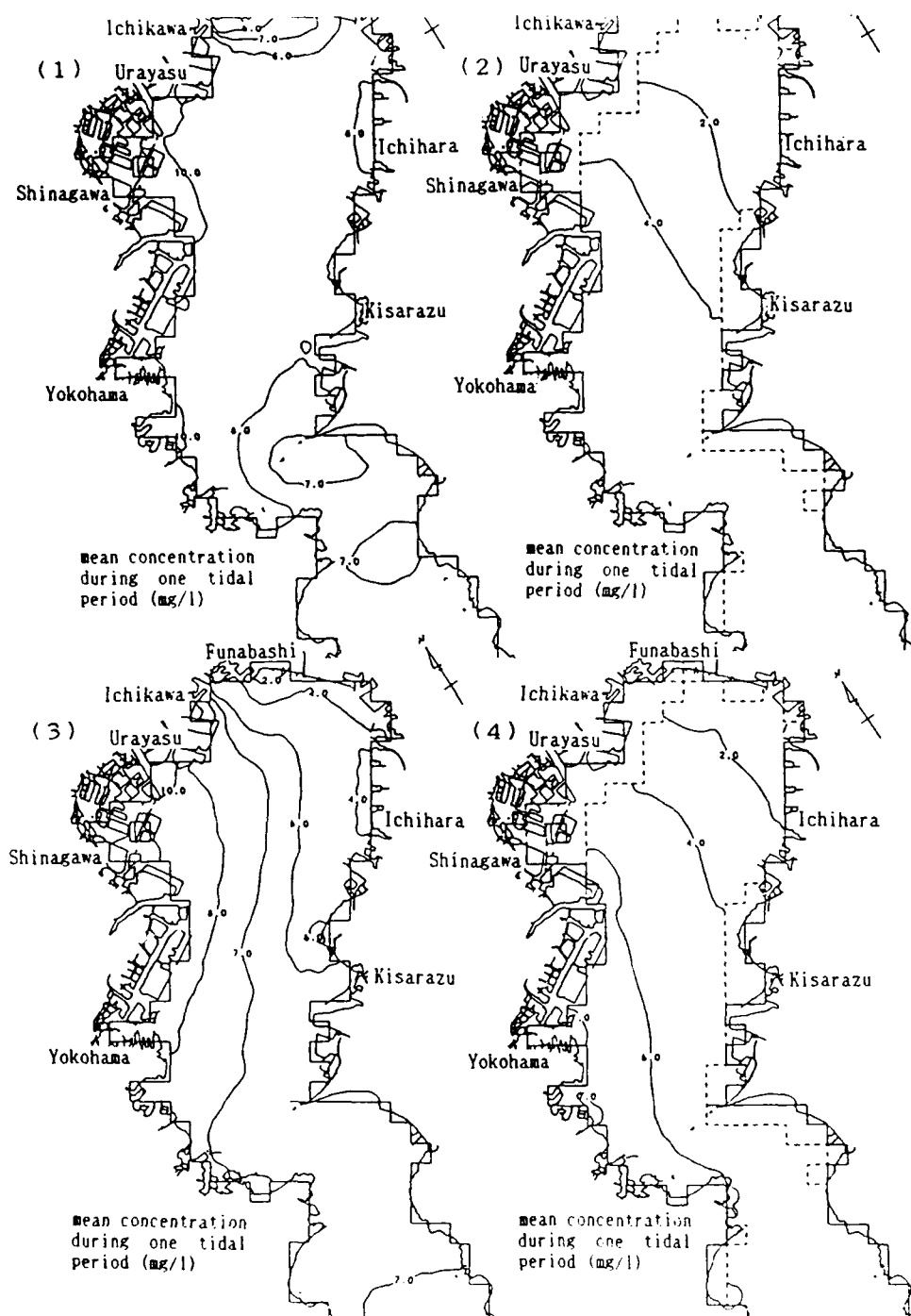
Step 2: Forecast the upwelling of an anoxic water mass  
(transport movement with northern wind)

The four-layer model of transport movement is shown in Figure 6 including tidal current, constant flow (residual current, density current, and wind drift current), and diffusion process of density. To calculate water quality, the model of nutrient cycle developed by the Port and Harbour Research Institute includes organic phosphorus, inorganic phosphorus, DO, and COD as indicated (Horie 1987). Here the behavior of sulphide is added to improve this model for better simulation of Aoshio.

In this model, layers are divided into four layers: 0- to 2-m depth, 2- to 5-m depth, 5- to 10-m depth, and below 10-m depth.

#### Definition of Aoshio in the Model

The state of anoxic water on the sea surface is treated as an index of Aoshio in this model. According to observations in 1987, the areas of Aoshio occurrence almost correspond to regions with DO concentration below 2.0 mg/l. The critical DO value of benthos survival, especially shellfish, is about 1.5 to 3.0 mg/l. Therefore, the definition of anoxic water mass is expressed by DO concentrations below 2 mg/l.



- Note: (1) First layer without wind.  
 (2) Fourth layer without wind.  
 (3) First layer with northeast wind, 5 m/sec.  
 (4) Fourth layer with northeast wind, 5 m/sec.

Figure 6. Examples calculations from forecasting model of Aoshio occurrence (DO concentration)

## Results of Calculation

### Simulation of Aoshio

Distributions of the DO calculated by our model are shown in Figure 6. On the first layer without wind, oversaturations of DO are found in all areas of Tokyo Bay except the mouth of this bay and the front of Funabashi. On the fourth layer, anoxic water masses with DO concentration below 2 mg/l cover widely in the inner part of Tokyo Bay, and an anaerobic water mass is found in front of Chiba Port. Next, the model with wind blow is expressed as follows.

After a duration of 2 days of northeast wind (5 m/sec), the anoxic water mass is shown in front of Funabashi. The simulation model of an Aoshio occurrence indicates good accordance with observations in 1987 (Figures 2 and 3). The areas with DO concentration below 2 mg/l on the fourth layer are reduced as compared with the model without wind. This phenomenon shows the effect of upwelling of the anoxic water mass near bottom in the inner part of Tokyo Bay.

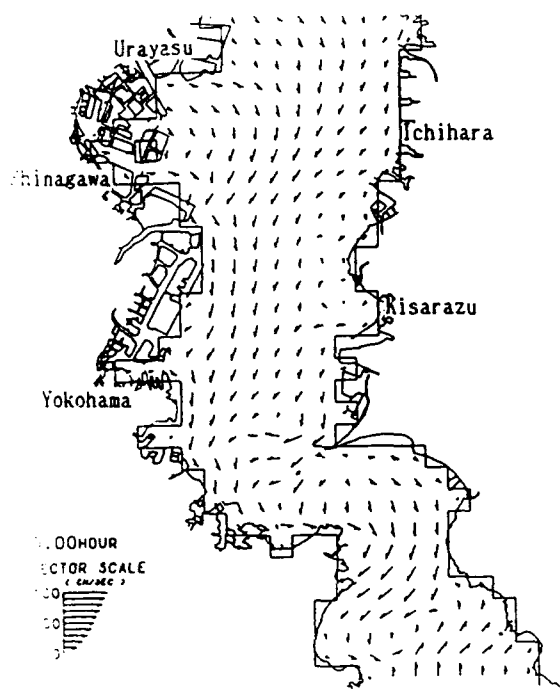
### Relationship Between Current Pattern and Contamination of Sediment in Tokyo Bay

In order to grasp the mean current pattern in Tokyo Bay, transport movement models are shown in Figure 7 during one tidal period. From the results calculated, some conjectures concerning current pattern can be given as follows.

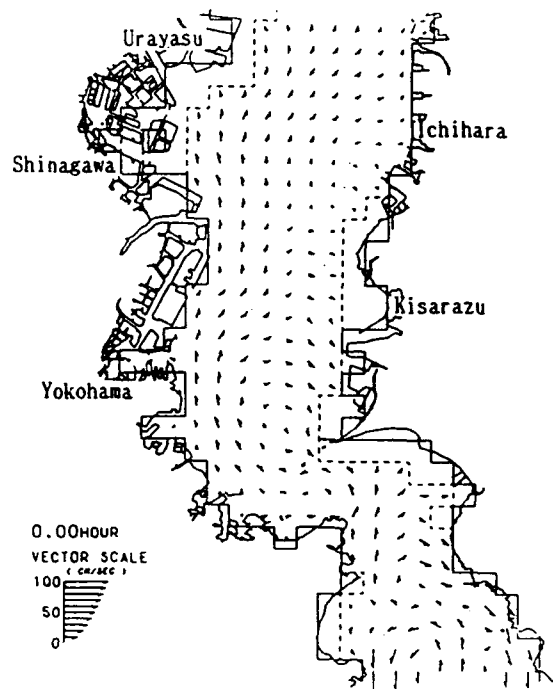
- a. The density currents produced by river runoff move from the inner part of Tokyo Bay to its mouth on the first layer but show the pattern from the mouth to inner part on the fourth layer (Figures 7a and 7b).
- b. Concerning the vertical movement of water, the remarkable descending motions are found in the central part of Tokyo Bay in the case without wind. It may have effects on distributions of sediment and the formation of an anoxic water mass. The organic matters discharged from Tokyo Metropolis or Kanagawa Prefecture flow southward with the surface current and gradually are descending offshore. As the currents on the lower layer flow northward, the environment near bottom in the inner part is degenerated because of the long stagnation of organic matter and its decomposition (Figures 7c and 7d).
- c. As descending motions also are found in the central part of Tokyo Bay with northeast wind, the same phenomena in the previous paragraph may be supposed (Figures 7e and 7f).
- d. Descending motions can be expressed, even with southern wind (Figures 7g and 7h).

As the mean state for long-interval flow, especially vertical motion, might have an effect on sediment distribution, the relationship between descending flow and sediment was discussed as follows.

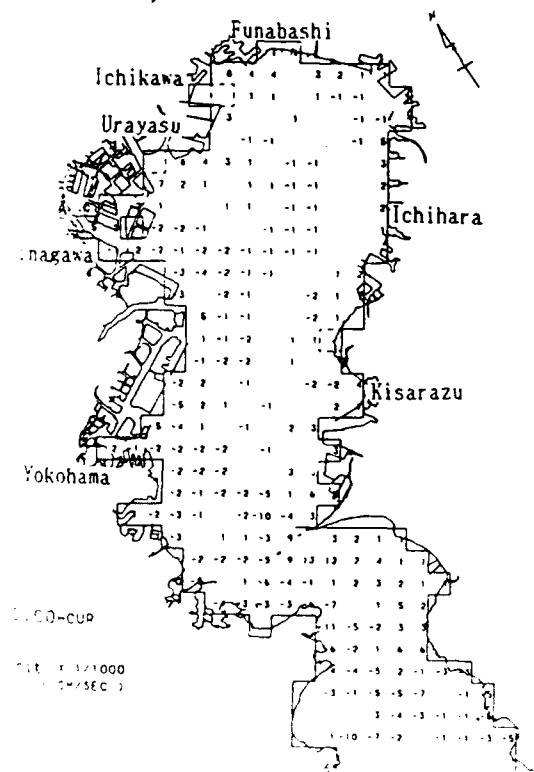
Ishiwatari (1988) studied the distributions of organic carbon in the bottom sediment in Tokyo Bay. These results are shown in Figure 8. It was



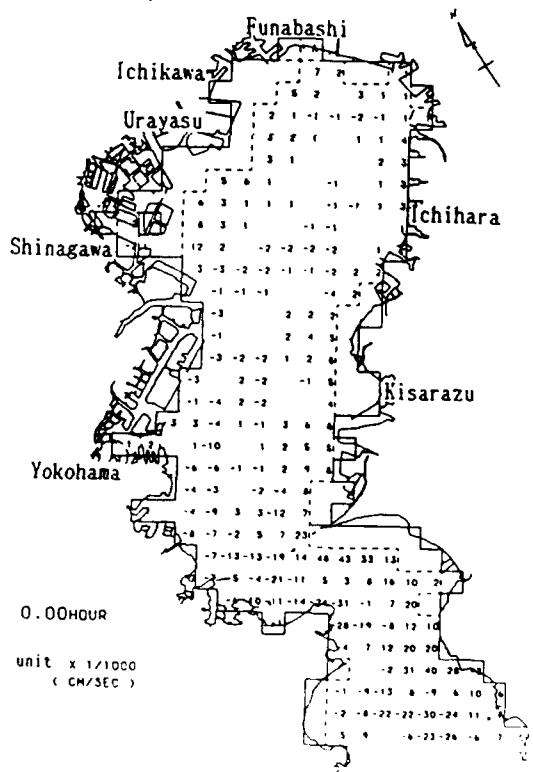
a. Transport movement on first layer (constant flow without wind)



b. Transport movement on fourth layer (constant flow without wind)

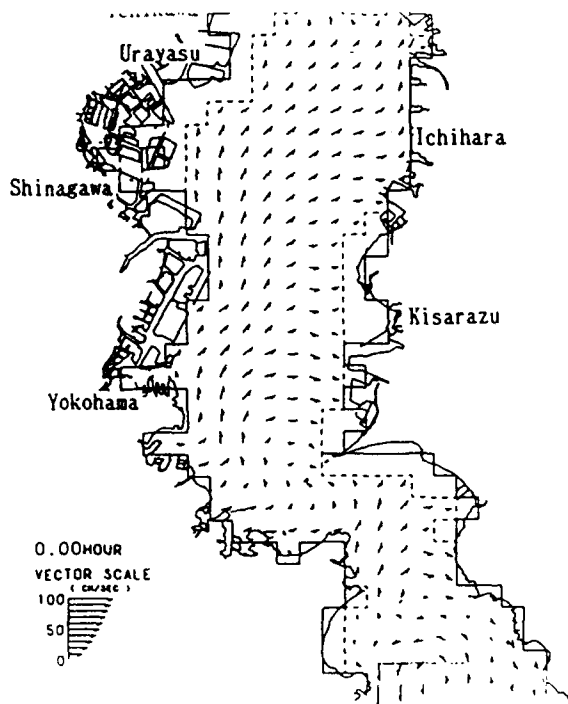


c. Vertical motion from second to first layers (constant flow without wind)

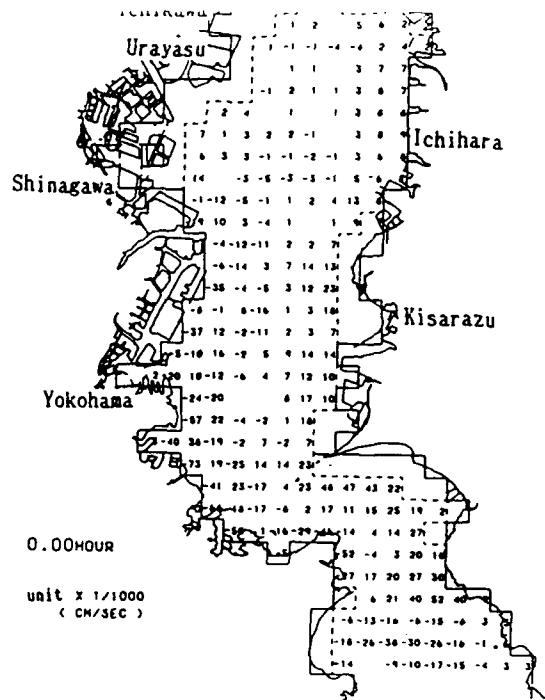


d. Vertical motion from fourth to third layers (constant flow without wind)

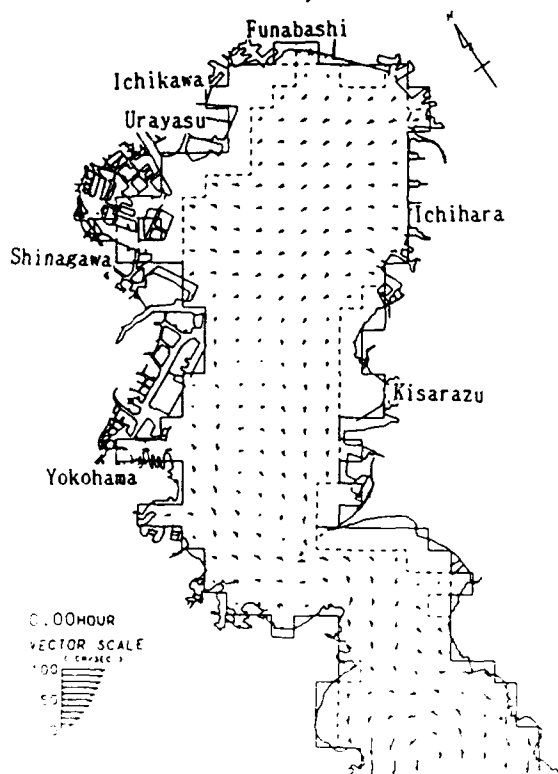
Figure 7. Simulation model of transport movement (Continued)



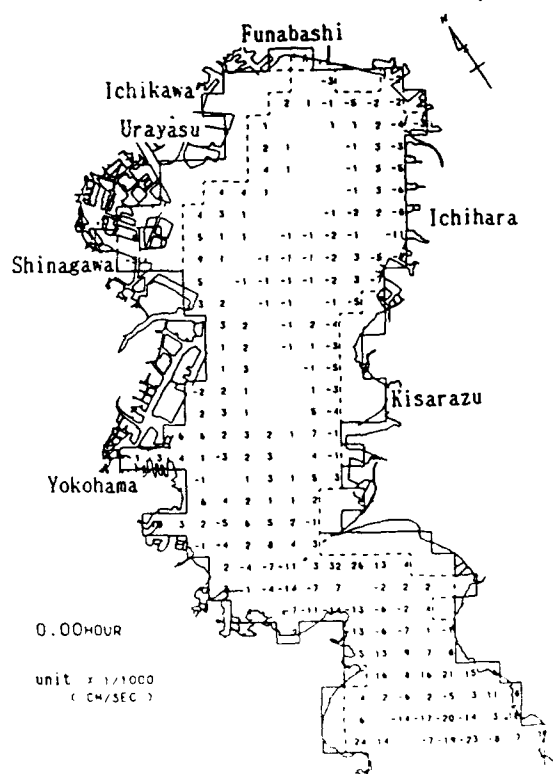
e. Transport movement on fourth layer (constant flow with northeast wind)



f. Vertical motion from fourth to third layers (constant flow with northeast wind)



g. Transport movement on fourth layer (constant flow with southwest wind)



h. Vertical motion from fourth to third layers (constant flow with southwest wind)

Figure 7. (Concluded)

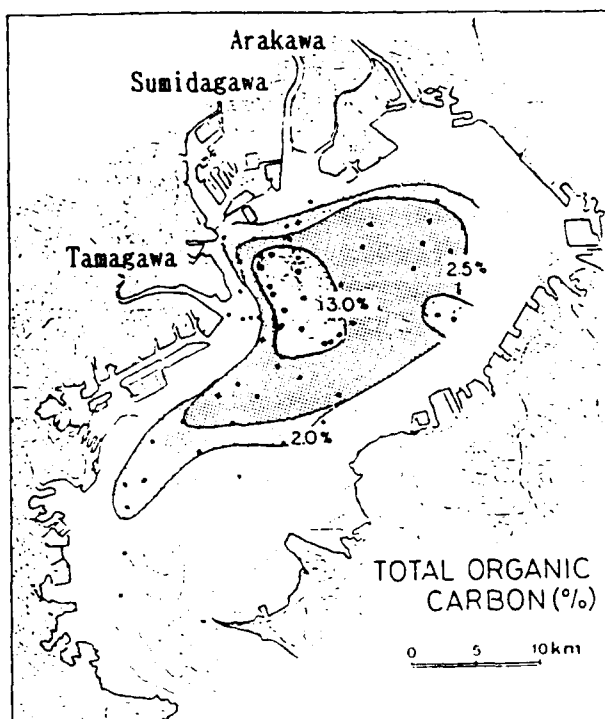


Figure 8. Distributions of organic carbon in surface sediment in Tokyo Bay (Ishiwatari 1988)

determined that most parts of organic matter in the bottom sediment of Tokyo Bay consisted of organic matter produced in Tokyo Bay, by comparison with carbon isotope data. By the comparison of distributions of organic carbon (Figure 8) with descending flow (Figure 7), it is obvious that a high concentration area may relate to distributions of descending flow in the central part of Tokyo Bay.

As descending flow is produced by either northern wind or southern wind in the central part of the bay, this flow may give suspending matters in water an easy sedimentation condition.

#### DISCUSSION OF MANAGEMENT PLAN FOR AOSHIO

##### Management Plans

Management plans can be designed for each objective, as shown in Table 2. Because the area of anoxic water mass appearance covers all interiors of Tokyo Bay, a big operation is needed to prevent an Aoshio from occurring. In consideration of environmental improvement, development of techniques, and utilization of the body of water, the possible operations to be realized will be the improvement of bottom sediment through dredging and capping, removal of organic matter in water, and local improvement works for special sites.

According to the results of the investigation in the past, the improvement of bottom sediment is the most effective method to realize the protection against Aoshio. Thus, dredging and capping are suitable methods.

TABLE 2. OBJECTIVES AND COURSES OF STUDIES FOR PROTECTION  
AGAINST AOSHIO OCCURRENCE

Objective	Targets	Management Plans*
Prevent Aoshio from occurring	Prevent anoxic water mass from occurring	Dredging and disintegration of stratified structure
	Prevent generation of sulfide	Dredging and disintegration of stratified structure
	Prevent generation of offshore current by wind	Set up surface current adjustment
	Prevent generation of onshore current in bottom	Set up bank on bottom
Protect the shell fishery	Make upwelling at distance from the shell fishery	Create ditches and banks
Protect the sea battling resort	Make upwelling at distance from the shell fishery	Create ditches and banks
Decrease frequencies of Aoshio occurrence	Prevent anoxic water mass from occurring	Sediment improvement
		Removal of organic matter
		Removal of nutrient loads
	Prevent upwelling	Accelerate mixing aeration
		Create submerged banks and ditches

\* Association of Fisheries Resource Protection in Japan (1978).

Since there are degenerated areas near the bottom, north of the line connecting Honmoku (Yokohama) with Ichihara (Chiba Prefecture) in the Tokyo Bay resulting from the input of contaminated discharges and the formation of an anoxic water mass, the amendment regions have been determined by values of COD and DO. These regions are shown in Figure 9.

#### Evaluation of Effects of Management Plans

Effects of management plans were calculated in three cases, namely, with northeast wind, northwest wind, and without wind. In order to demonstrate the effect of a management plan, the difference of DO values between the plan (calculated plan) with hypothetical dredging and capping is compared with present situation (Figures 10a and 10b). From these results, it is noted that DO values after the management plan increase by 1.0 mg/l over the value of the present situation on fourth layer without wind. The areas of anoxic water masses are reduced.

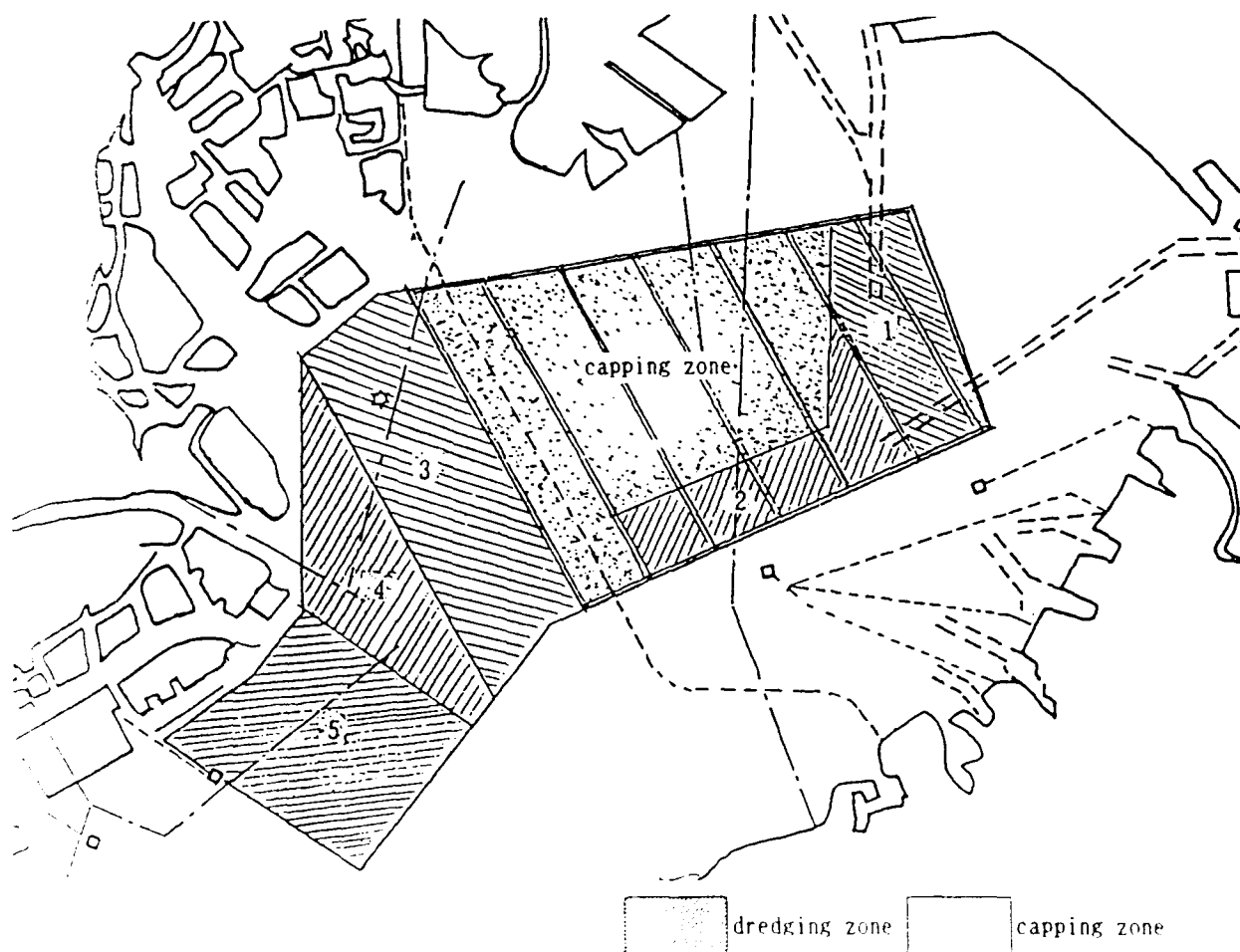
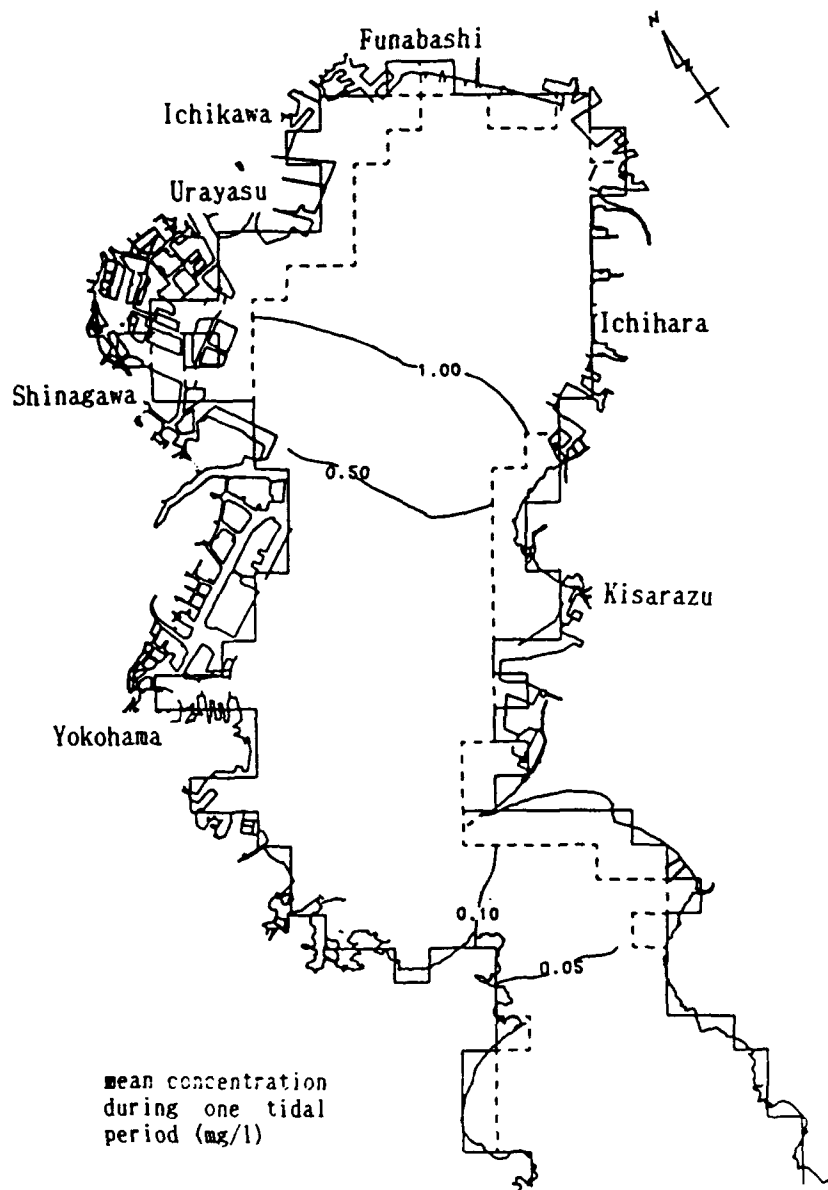
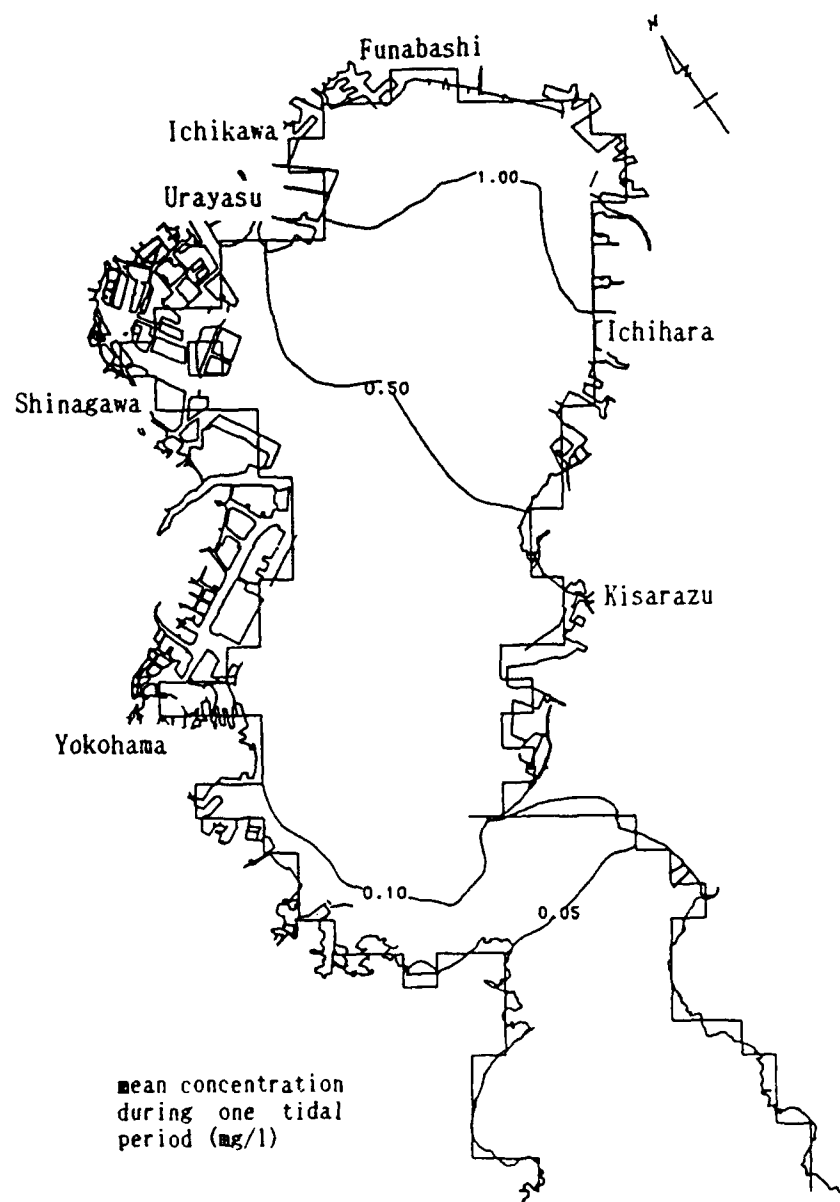


Figure 9. Proposed areas for dredging and capping



a. Without wind

Figure 10. Increase of DO on fourth layer after management plan (difference between executing the management plan or not) (Continued)



b. With northeast wind

Figure 10. (Concluded)

Following this model, the anoxic water mass disappears even in front of Funabashi in spite of the suitable condition of Aoshio occurrence with north-east wind. In the example with northwest wind, the same phenomenon previously mentioned can be obtained. Under various examinations with the management plan, the areas of anoxic water mass calculated are exhibited in Table 3.

Although from this table areas of anoxic water mass without wind were 176 sq km concerning field data on fourth layer, they will be reduced to 28 sq km after the management plan. Thus, the effect of the management plan should be verified by comparison with field data.

#### Annexation Effects with Management Plan

If dredging and capping are carried out with the same conditions under the management plan, annexation effects in the following will be produced.

TABLE 3. AREAS\* OF ANOXIC WATER MASS UNDER VARIOUS CONDITIONS

Wind Conditions by Layer	Layer			
	1	2	3	4
Present state without wind	0	28	80	176
Present state with northeast wind	8	44	60	92
Present state with northwest wind	8	40	36	168
Management plan without wind	0	3	4	28
Management plan with northeast wind	0	8	4	16
Management plan with northwest wind	0	8	4	16

\* Values expressed in square kilometers.

#### Reduction of Regeneration from Bottom

Reduction values of regeneration from the bottom are shown in Table 4 in consequence of dredging and capping over 200 sq km. As noted, these values as proposed are very effective and important.

TABLE 4. REDUCTION VALUES OF WATER QUALITY OVER THE AREAS  
OF DREDGING AND CAPPING

Parameter Item	Reduction Value of Regeneration ton per day	Ratio for Regeneration in All Areas percent	Ratio for Loading from Inflow percent
COD	39.0	38	15
Total phosphorus	2.08	30	8

#### Effect of Water Quality Improvement in Tokyo Bay

DO concentrations in summer will recover about 1 to 2 ppm than the preceding condition, and occurrences of anoxic water mass will be improved. COD concentrations also will be improved over all areas of Tokyo Bay (lowering about 0.3 ppm), and the transparency of water recovered will be about 0.3 m higher than before. Under these conditions, it is possibly enough to show a good living state for benthos.

#### Removal of Nutrient (Withdrawal of New Sediment)

The removal of nutrient will be estimated to be 23.5 tons per day in nitrogen and 5.4 tons per day in phosphorus on the supposition of a sediment withdrawal of 1,270,000 cu m per year. These values correspond to about 9 percent and 27 percent for total loading of nutrients to the Bay, respectively. These results should contribute to the decrease of eutrophication in the Bay.

#### Estimate Cost for Management Plan

The costs to realize this plan are calculated to be about 25 billion yen (\$180 million US) in Table 5.

#### Synthetic Estimation

According to this management plan, it may be asserted to reduce remarkably the regeneration values from the bottom and provide some protection effect for Aoshio.

As the cost is estimated to reach an enormous value, the effects of this plan do not remain for a long interval and will possibly diffuse widely over all areas of Tokyo Bay. Now it is difficult to realize this plan as the national project.

TABLE 5. ESTIMATE COST FOR MANAGEMENT PLAN

<u>Management Plan</u>	<u>Area km<sup>2</sup></u>	<u>Cost million yen</u>
Dredging	120	121.000
Capping	80	108.500
Withdrawal of new sediment	120	25.800
Total		255.300

To make improvement in water quality conditions of Tokyo Bay, another method also should be considered such as the curtailment of nutrient loading from river and drainage. Recently, the recovery of natural environment has encouraged interest from the global viewpoint. Following these currents in the world, an increasing concern for this project is expected as one link of global environmental problem.

#### CONCLUSION

The general scenarios of forecasting a model for Aoshio occurrence in Tokyo Bay were elucidated on the basis of field studies in 1987. Tokyo Bay is one of a few calm natural waterfronts left near the modern big city.

To apply this bay to fisheries or maritime recreation, it is an urgent problem to carry out the improvements of water quality and bottom sediment including protection of Aoshio.

The Second District Port Construction Bureau, Ministry of Transport, would like to continue the research and investigation in Tokyo Bay and endeavor to realize this project.

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PROPOSAL OF THE SEA-BLUE PROGRAM--  
APPLICATION OF NATURAL ENERGIES AND BIOLOGICAL  
ACTIVITIES TO WATER QUALITY IMPROVEMENT ALONG COAST

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ABSTRACT

For waterfront development in inner bays, it is essential to improve water quality so as to meet social needs for comfortable coast environments.

A concept of creating a new water-affinity space along a shallow coast is discussed with the consideration of sea surface as an attractive environmental resource. Economical water purification should harness natural energies (tide, waves, wind, etc.) as well as biological activities (microbial film, macrophytes on tidal marsh, shells, etc.). Case studies were also conducted and showed that our new idea called "SEA-BLUE Program" will be feasible in the near future.

INTRODUCTION

In Japan, social needs for easy access to comfortable waterfront recently become stronger with the change of the life style of urban citizens. In this paper, we propose a new concept to purify the surrounding water for the waterfront to provide citizens with an environment more suitable to its utilization. We try to apply the "goal-setting"-type approach instead of the conventional "problem solving"-type one. From the strategic point of view, we believe that the former approach is quite powerful for (a) awakening social needs, (b) making aerial development concept, and (c) rearranging the present technology more clearly to identify the objectives for technological development (Kondo et al. 1989). This approach also requires the consideration of economical water treatment. We are trying to use natural energies and biological activities which are found easily at shallow coasts. For realistic researches, we conduct some case studies of conceptual designs, which do not necessarily mean real projects.

SOCIAL NEEDS FOR COMFORTABLE WATER SURFACE

Water affinity or accessibility can be categorized into the following three levels: (a) watching the sea surface, (b) touching water by feet and/or hands, and (c) bathing in the water. The utilization level will vary from place to place depending on natural and social conditions as well as



environmental conditions. Thus, the environmental goal to be achieved will vary depending on each utilization level.

The Yokohama City Port Bureau conducted a survey of its citizens concerning the port affinity. The major part of the public coastal area in this port is arranged for the watching level. They recognized the Port as an attractive, enjoyable, and clear open place. At the same time, they also pointed out the water pollution near the shore and inconvenience for marine sports. They claimed, first of all, protection from the water pollution rather than the traffic accessibility or the citizen's markets. The Prime Minister's Office, the national government, made another survey for the visitors to ports and beaches. They were dissatisfied with the garbage on the beach and the turbidity of water. A study of people's requests for waterfront and regional development shows that "purification of organic contaminated water alongshore" gets first priority (Figure 1).

These surveys make it clear that citizens expect a more comfortable coastal environment and that the actual condition of the present coast near urban areas needs some measurement to purify water. High water quality, which is suitable for its utilization, is now requested even for the watching level. On the other hand, improving the quality will promote utilization of the citizens as well.

#### BASIC CONCEPTS FOR CREATING COMFORTABLE COASTS

This report deals with the coastal sea water. The sea has its own attractiveness and gives much relief and comfort under well-arranged conditions. Five basic concepts for arranging conditions to achieve more attractive and comfortable scenery are described below.

The first concept is "encouraging natural characteristics of the sea." The natural characteristics of the sea are, for example, enormous mass of water, wide open surface, large relative heat and heat capacity, rich in salts and ions, waves and tides, and various kinds of livings. All of these are impressive and make us feel relaxed due to its width, the open sky with sea gulls, cool fresh winds, salty smells, and regular sounds of waves and shells on a beach. Even though it is much easier to improve water quality in a tiny swimming pool, it is less comfortable.

The second is "creating and enhancing good conditions intentionally." The sea has the potential in itself to attract people. Efforts are being made to help express the attractiveness of the sea by managing the coastal environment. Port and/or beach protection facilities will be designed in a useful way for improving water quality and accessibility.

The next is "making mutual connections between land and sea." Much stress has been placed on the prevention policy from coastal disasters, such as high surges, wave attacks, and Tsunamis. It often happens that people living nearshore can hardly see the water surface because of high seawalls. The disaster prevention facilities should harmonize with the easy access to the seawater. Floating bridges, artificial beaches, and offshore banks could be ideas for improving accessibility.

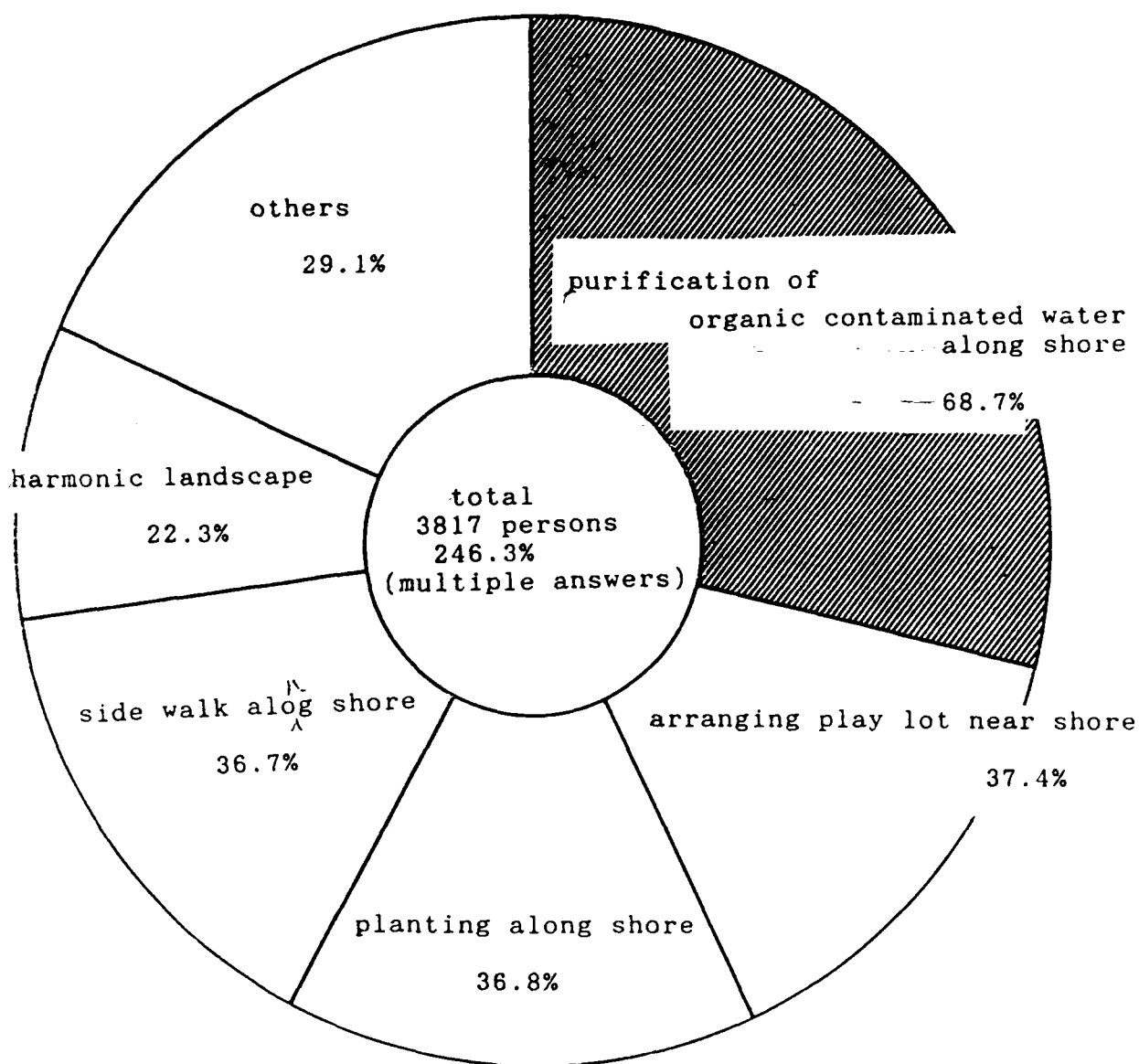


Figure 1. Results of survey of people's requests for waterfront and regional development

The fourth is "maintaining water quality suitable for its utilization level." Water quality indices originally express the degree of inconvenience for a certain utilization. The watching level requires less turbidity and better smell quality, which is naturally different from the quality for bathing. Considering the utilization of coastal areas will mean identifying the users who enjoy good circumstances. If the persons who should pay for improving environments can be identified, the cost-benefit relationship and financial planning could be discussed more easily.

The last is "combining countermeasures economically." The water quality along the coasts is lower in concentration and larger in water mass than that in the rivers and lakes. It is difficult to apply the techniques of the sewage treatment directly to coastal water. Copying purification functions of

the natural coast would be effective. Utilization of the natural energies and biological activities is economical for us to promote and maintain higher purification ability. This idea indicates a direction for the research and development on environmental technology. This policy also introduces a way to increase environmental capacity along the coasts from the viewpoint of environmental management.

#### VALUE OF ENVIRONMENTAL RESOURCES AND PROGRAMMING FLOW

Evaluating methods to determine the economical value of environmental resources have been studied for a long time. The theory of willingness-to-pay is a good stimulus. Now there is more interest in the whole image of programming flow, as shown in Figure 2. In Figure 2, all the feedback lines are erased. This flow is composed of several steps from the object-setting to the technical-solution, which is followed by the final goal of areal designing. The process of each step is briefly described as follows;

- Step 1: Grasping social needs and present requests for the assigned coastal area.
- Step 2: Research on the natural and social conditions and the present environment.
- Step 3: Expressing the request as a catchword (e.g., the sea where we can swim).
- Step 4: Making the object clearer by the selection of environmental elements (water quality, sediment quality, current, wave, etc.) which can affect and disturb the request sensitively.
- Step 5: Giving actual indices to the selected environment elements and making them possible to measure (COD, turbidity, coliform, etc.).
- Step 6: Assigning each index an actual value or concentration which suits the utilization of the water surface (COD <2 mg/l, coliform <1,000 M.P.N., etc., for swimming level).
- Step 7: Choosing and combining technical measures to satisfy the required environmental level.
- Step 8: Evaluating the requested level, techniques, and dimensions from the viewpoint of designing feasibility.

For Step 7, the purification techniques are separated into three groups: (a) techniques which remove or degrade pollutants from the water body (e.g., rock filter with biofilm, macrophyte vegetation, etc.), (b) techniques which disperse or transport pollutants from the concerned area (e.g., regulation of tidal flow by breakwaters), and (c) techniques which maintain or promote the above two (e.g., construction of shallow marsh with macrophytes). Matrices of various kinds of purification techniques, purification principles, and available natural energies are prepared, because these will be useful for the combination of techniques.

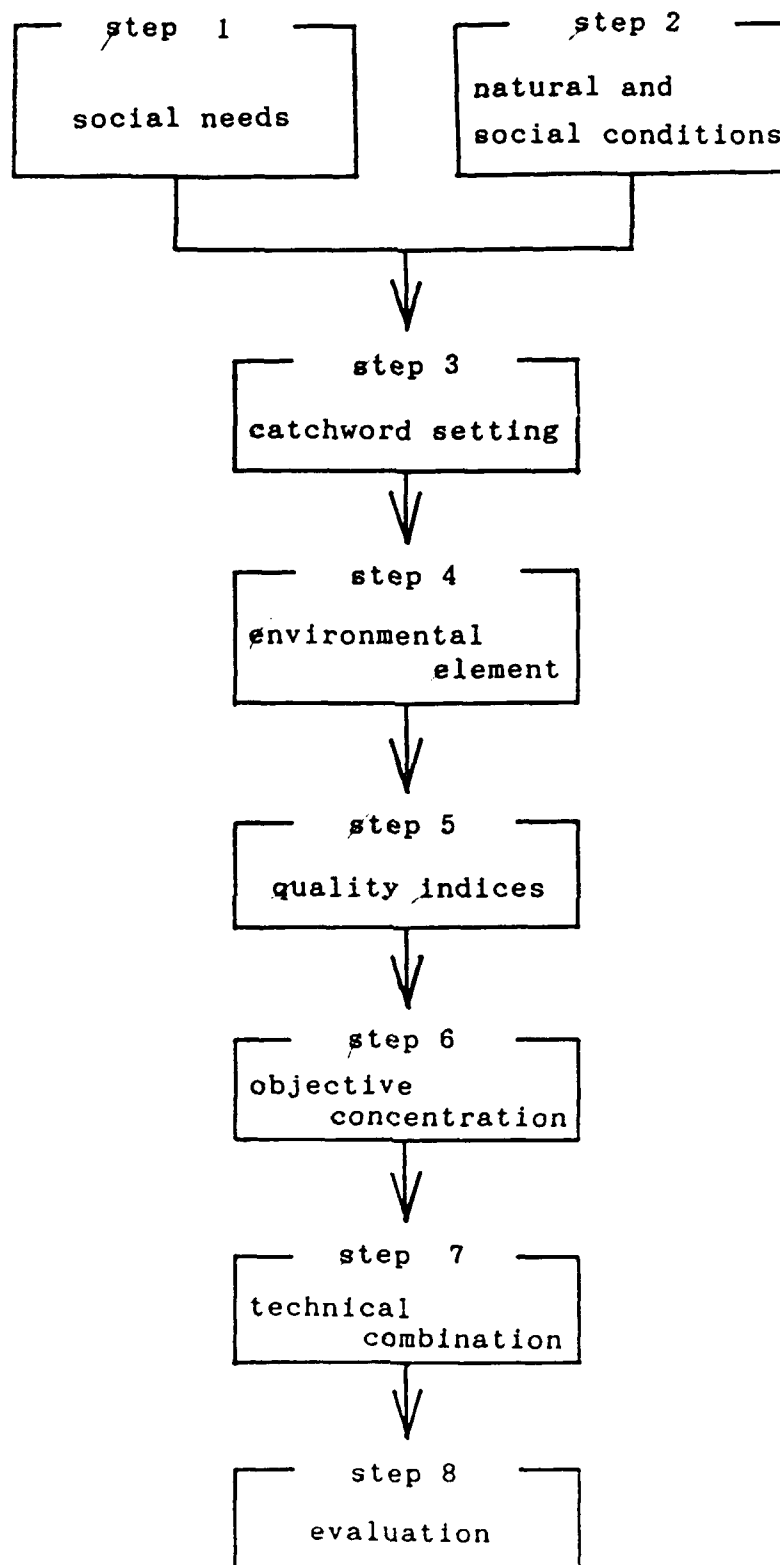


Figure 2. Programming flow

## CASE STUDIES

Five areas for case studies were selected in order to give more actual images to the programming flow. Two of the five areas are located at the bottom of Tokyo Bay, and three along Mikawa Bay. These two are typical eutrophic bays.

### Ariake Area in Tokyo Bay

This area has abandoned shallow canals which were once used as the main surface routes and stock surface for woods. It is located near the metropolitan area. The Tokyo Metropolitan Government has a rehabilitation plan for this to be a residential area with office areas nearby. The water quality of this canal is worse in summer ( $\text{COD} \sim 6 \text{ mg/l}$ ) due to the high primary production of plankton. The catchword is "harmonic symphony between sea and man at urban oasis," which means introducing attractiveness of the sea into the urban area. Water quality, accessibility, and landscape were selected as important environmental elements to present a more comfortable waterfront. The utilization level is set as mainly watching (and touching at some part), and COD (chemical oxygen demand) and DO (dissolved oxygen) are chosen for representative water quality. The objective standard assigned for these concentrations were:  $\text{COD} < 4 \text{ mg/l}$  and  $\text{DO} > 2 \text{ mg/l}$ .

Areal designing principles are as follows: (a) leaving present water surface as wide as possible to get better sight and landscape, (b) keeping former breakwaters as they are because of dense natural woods on them, and (c) arranging an artificial beach and marsh along the canal, a pedestrian wall, and/or bridge over the canal to enable citizens to access water easily. Figure 3 shows the zoning of this area. The water surface area is about 46 ha, and the water volume is roughly 1,000,000 cu m.

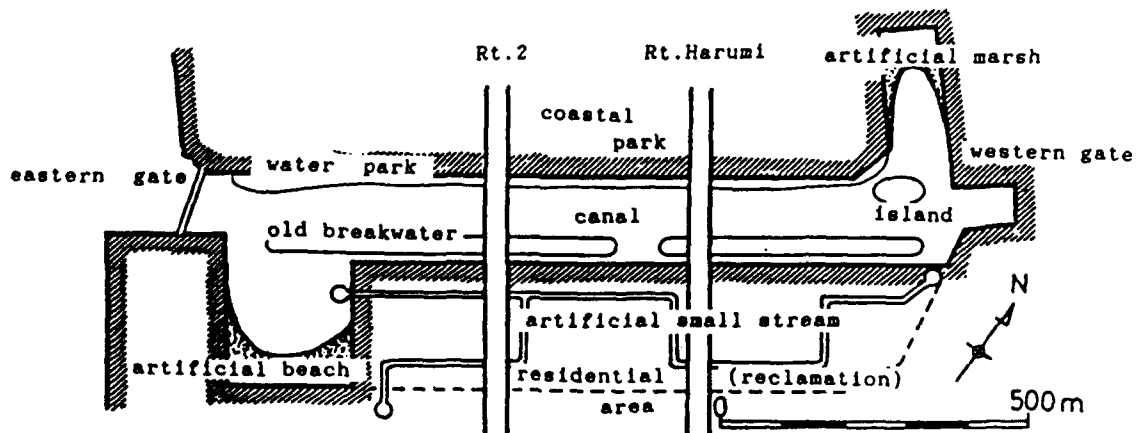


Figure 3. Facility arrangement of Ariake area

Technical considerations for the water quality and flow management were made as follows: (a) dredging organic sediment followed by sand capping, the most effective method of lessening nutrient concentration in the canal due to its shallowness (mean depth, 2 m) and low water exchange, (b) enclosing the canal water by east and west gates loosely to separate the improved water from

surrounding eutrophic water of the inner bay, (c) introducing surrounding water after purification into the canal and making one-directional flow (from the east island to the west gate) through the canal to exchange water (hydraulic retention time, 50 days), (d) making small tidal movement ( $\pm 10$  cm above/below m.s.l.) in the canal to support the biological activity at the artificial marsh, and (e) for above treatments (c and d), utilizing tidal energy (tidal range for M2 component - 1 m) which is easy to pick up and rich around this area.

Figure 4 is the schematic map of the water flow with the combination of purification facilities. Purification facilities besides the capping include: (a) artificial seagrass woods in front of the western entrance gate, (b) an underground rock filter waterway under the pedestrian sidewalk, and (c) an artificial marsh at the east end. The water mass intake is about  $210,000 \text{ m}^3/\text{day}$ . Total area of the seagrass leaves is  $3,200 \text{ m}^2$ , expecting 20 or 25 percent solid separation efficiency. Total length of the rock filter way is set at 1.5 km, expecting 60 percent removal of COD from the experimental result for fresh water (Horasawa 1979). A coagulation treatment process can be applied, if necessary, after the rock filtration (33 percent removal for COD and SS). Water quality can be evaluated by the numerical simulation assigning the efficiency of each process. Predicted concentration of COD is presented in Figure 5 for each option of the combinations. Option 1 shows capping with 20 percent removal at seagrass woods and rock filtration. Option 2 expresses capping with 25 percent removal at seagrass woods and rock filtration. Option 3 is added to a coagulation process after filtration based on the second option. DO concentrations were calculated in the canal to make sure that each DO is high above  $2 \text{ mg/l}$ . The result showed that  $\text{COD} < 4 \text{ mg/l}$  can be attained in this canal. A conceptual view of this areal development plan is shown as Figure 6.

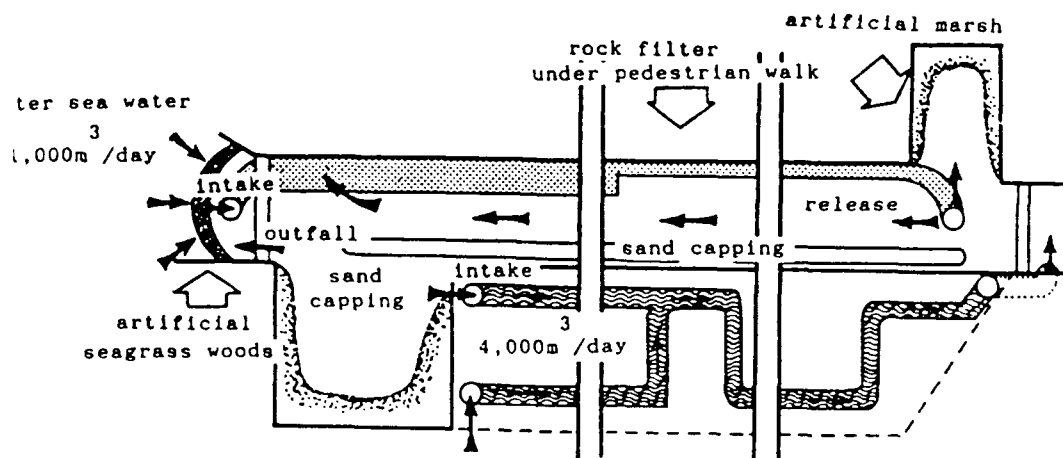


Figure 4. Schematic of water flow and purification facilities (black arrow is water flow; white arrow is facility)

#### Yokohama Inner Port in Tokyo Bay

A river mouth at the inner port of Yokohama was chosen as a study area, for this river has a waste treatment plant at the upper part and is the

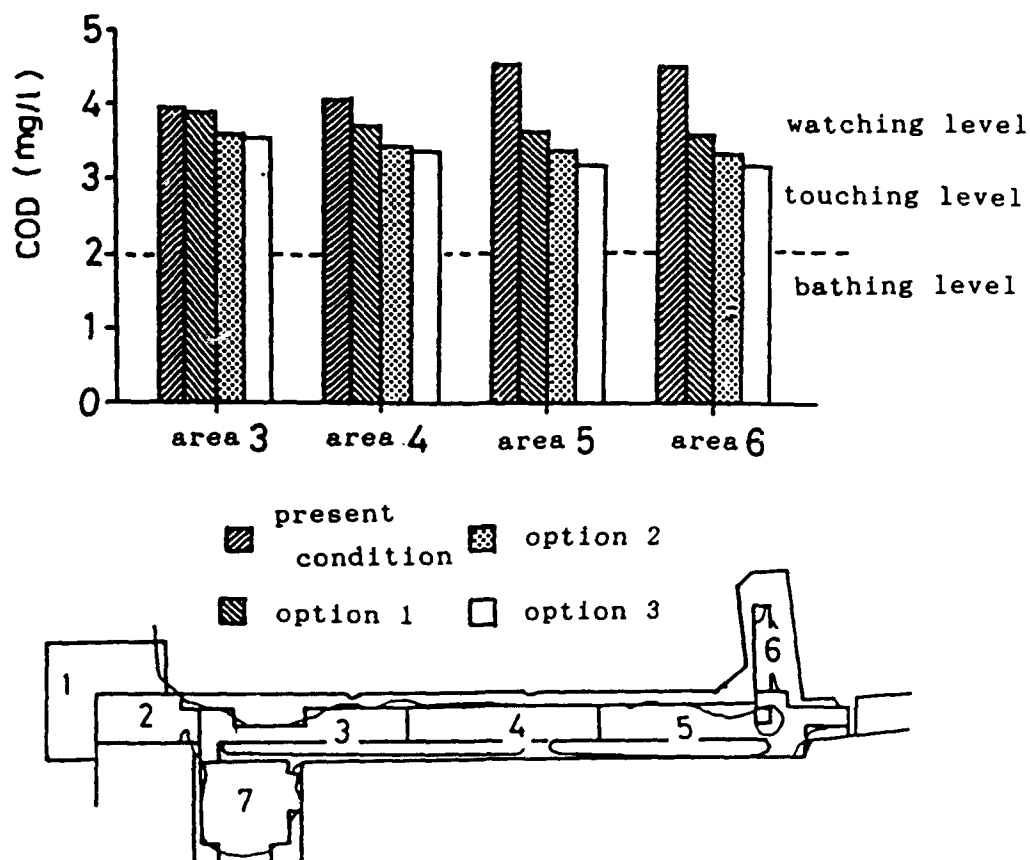


Figure 5. Predicted concentration of COD in each area (see explanation of options in the text)

dominant pollutant source to the mouth area. This area (13 ha) is now surrounded by wharves and bank walls. Yokohama City has a big rehabilitation plan called "Minato Mirai 21" (MM 21), and this water surface is expected to be an open space with water affinity. But, in summer, the water quality (COD 5 to 6.5 mg/l, transparency 1.7 m) is not good enough for skin contact. The catchword is "the creation of water affinity in the urban area." The objective is set as "touching," and transparency is selected for the environmental element. The critical standard for this level is estimated as 2 m.

Dredging and capping are effective here, too. The water quality of the bottom layer off Yokohama Port is low in COD and DO even in summer. Another measure is to introduce this bottom water into the river mouth after aeration by artificial falls or a fountain. A basic but expensive solution is to lessen river load. Two measures are considered: partial sand filtration of the river water at the upper point, and a change of the riverflow route near the mouth. Three kinds of combinations (option 1: capping + introduction of the outer water; option 2: option 1 + river purification; option 3: option 1 + change of the river route) are evaluated by numerical simulation. A transparency of 1.8 to 2.2 m is obtained for option 1, and above 2.5 m for option 2. Option 3 made a low-quality spot within the surface and is not suitable for our objective.

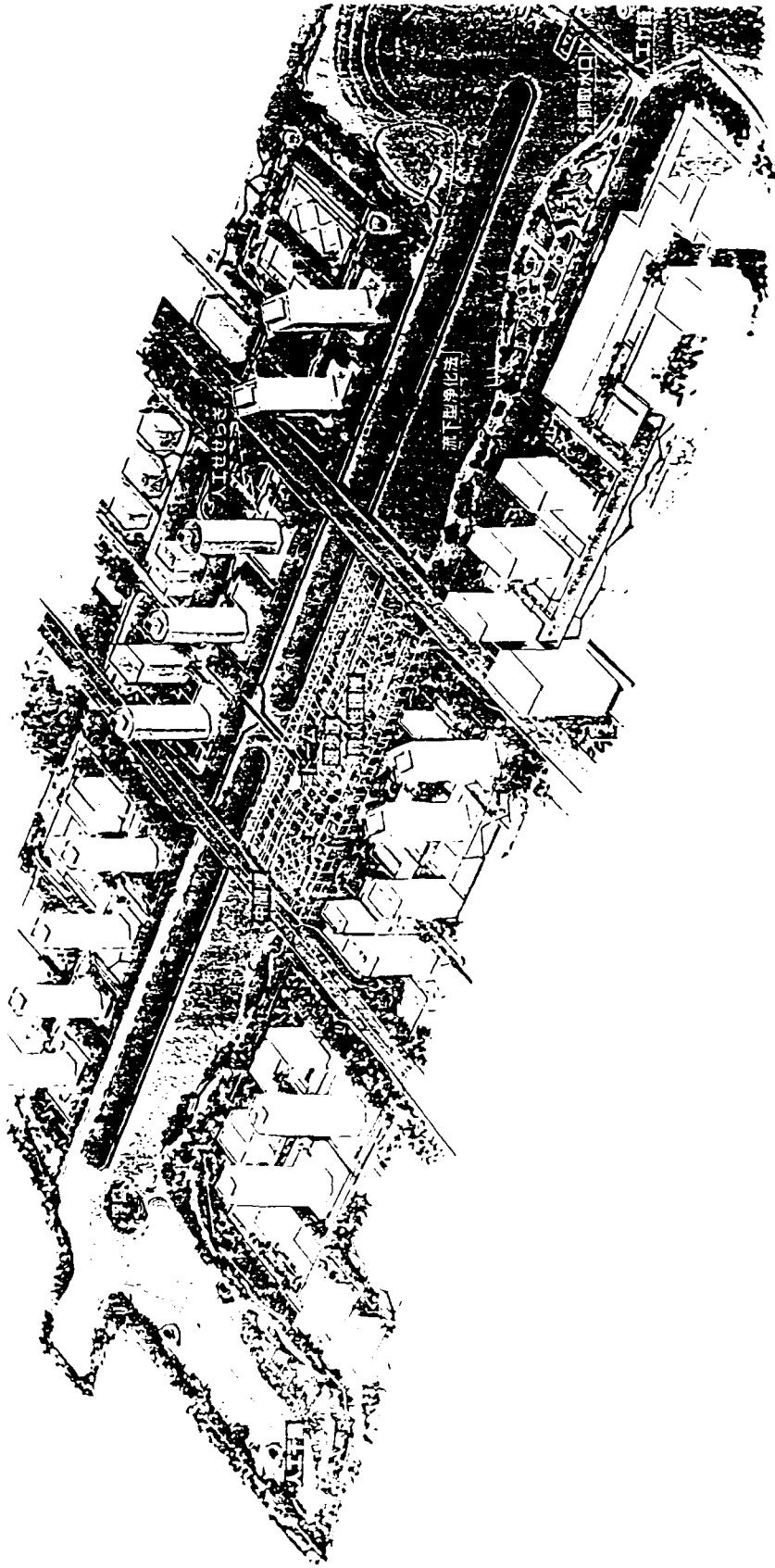


Figure 6. Conceptual view of Ariake area development

### Takeshima Island in Mikawa Bay

Both Takeshima and Ootuka areas belong to Gamagouri City, which faces the Mikawa Bay and is very attractive for its mild climate and long shallow coastal line. Takeshima Island is famous for its beautiful sights and the old shrine there. Many visitors from Nagoya visit this island and play at the beach and coast near the island. However, the high seawalls and unpleasant odor of drifted seagrass (Aosa) on the beaches are two unattractive features to visitors. Water quality is good enough, for "touching level" at present.

"Come to Gamagouri" is a catchword for both Takeshima Island and Ootuka beach areas. Important environmental elements for Takeshima Island are easy accessibility to the beach and beach protection from drifting seagrass. High productivity of the seagrass is a result of eutrophication of the Mikawa Bay. Dredging and capping along the shore is the first measure. Flow regulation is most effective for beach protection from seagrass. A flow generator from the tidal energy is to be installed off the beach with deep trenches and curved jetties for flow regulation. All these facilities will promote one-directional flow parallel to the beach. At the mouth of the flow generator, a cropping stand with wire mesh fence will collect drifting grass. A numerical simulation of drifting markers shows that 80 percent of the markers which arrive at the beach under the present configuration are caught at the cropping stand.

### Ootuka Beach in Mikawa Bay

Another goal set was arranging the bathing beach with "bathing level" water quality for the case study of this area. Bathing beaches along this coastal line were difficult to find due to the eutrophication. A bathing beach here is expected to increase visitor numbers. Representative environmental elements for this goal are COD of water quality and accessibility to beach in harmony with prevention from high surge. The objective concentration for COD is set as 2 mg/l.

Water quality in surrounding water is 3 mg/l in summer and a little different from the objective concentration. Then, the bathing area and artificial beach are designed to be enclosed by an offshore bank. This bank has a wide crown (used as a pedestrian walk) and water purification ditches. The tide makes head differences between the outer sea and the bathing area. At flood tide, water from the outer sea is introduced into the bathing area through purification ditches. At ebb tide, water from the bathing area goes out through a submerged gate. Hydraulic retention time for this system is estimated to be 1 week. Tidal range in the surrounding water is also estimated to be 30 percent as high as that in the outer sea. Numerical simulation shows that the effect of the purification ditches is not enough to satisfy the objective goal. Associated capping on the bathing area and some ecological effect on a sand beach are needed to gain the high quality of COD <2 mg/l.

### Tahara Area in Mikawa Bay

Tahara area is located on the Atsumi Peninsula, which separates Mikawa Bay and the Pacific Ocean. This area has a long beach (1 km) facing the eutrophic Mikawa Bay. Water quality in summer is COD 3 to 4 mg/l, which is not suitable for bathing. Our goal is set to create a bathing environment

(COD <2 mg/l) for the wide water surface (L = 1 km and W = 500 m). At the Pacific Ocean side, there is much clearer water (COD 1 to 1.5 mg/l) as well as enough wave energy (H mean = 0.84 m). Using this wave energy, water introduction from the Ocean is planned. Waves (H >1 m) are collected by a shore slope to get a higher elevation (+3 m). The outer water goes down across the Peninsula (6,500 m) to the receiving pond of the Tahara area. If flow of 7 m<sup>3</sup>/sec is attained, the water quality in the bathing area becomes COD 1.5 mg/l. The change of salinity concentration is calculated to be small. The total effect to the whole Mikawa bay remains unknown.

## CONCLUSIONS

### Economical Point of View

An estimation of the required cost for the construction of purification facilities at each study area was made, and the results are shown in Table 1 along with natural and social conditions. Our programming flow can be applied for various natural conditions and water quality. When the results were compared, it was more expensive to improve the worse quality of the wider area, as expected. Plans should be evaluated again for the area, and goals set on the basis of cost.

### Technical Objects

In Table 1, main facilities for environmental improvement are also summarized with each technical feasibility (from A, available now, to D, may be available in the future). Among various ideas, the importance of biofilm and flow regulation technologies is noted. Rules for the combination of facilities are also essential.

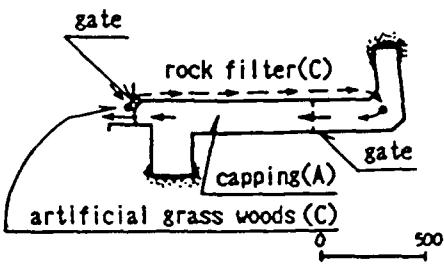
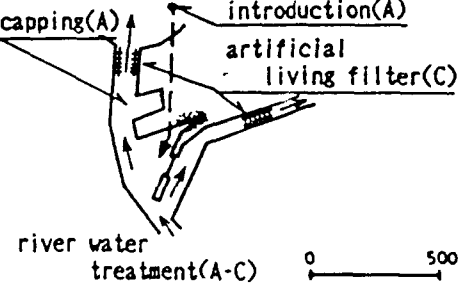
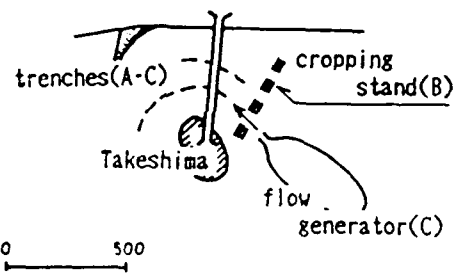
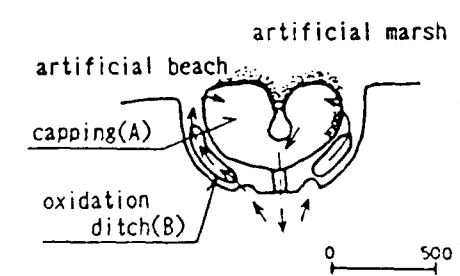
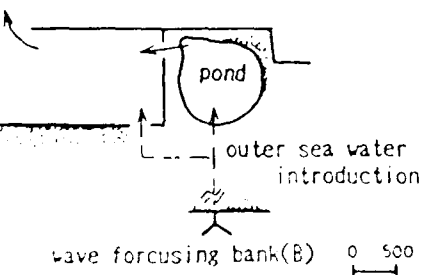
### Environmental Management

A numerical study (Horie 1988) has already shown that changing the coastal features in an enclosed eutrophic bay affects the water quality near and off the coast. Accumulation of the waterfront treatments for environmental improvement will have a good effect on the water quality of the whole bay. This effect will be estimated as an increase of the environmental capacity of bay.

## ACKNOWLEDGMENTS

This research was conducted with the advice of Professor Y. Goda, National University of Yokohama; Professor T. Sakoh, Tokai University; Professor M. Shimizu, University of Tokyo; Associate Professor T. Maruyama, Fishery University of Tokyo; and Associate Professor T. Kondo, Nihon University. We appreciate their advice and encouragements. We also express our appreciation to the young engineers of the Japan Sediments Management Association, who devoted their effort to the research and design. A part of this paper was presented to the 36th Conference of Coastal Engineering, JSCE (Goda et al. 1989).

TABLE 1. SUMMARY OF CASE STUDIES

area	natural condition	「catchword」 (object level) main attractives	proposed system for environmental improvement (A~D: technical feasibility)	environmental facilities area/cost (ha)(10 <sup>4</sup> YEN)	water quality improvement
Arlake	eutrophic canal	「harmonic symphony」  (watching)  side walk, water park		83 / 89	COD (mg/l) 4~6.2 ⇒ 3.2~3.8  DO (mg/l) 1.4~7 ⇒ 3.3~8.8  transparency ⇒ 1.8m
Yokohama	river mouth	「water affinity」  (watching)  side walk, boating		13 / 68	COD (mg/l) 5~6.5 ⇒ 4  DO (mg/l) 4~8 ⇒ 7.0  transparency 1.7m ⇒ 1.8~2.5m
Takeshima	open beach	「Come to Gamagouri」  (touching)  shell hunting Takeshima Shrine		60 / 35	80% of drifting grass is removed
Ootsuka	high seawalls	  (bathing)  bathing beach		33 / 73	COD (mg/l) 3.4~4.9 ⇒ ~2  DO (mg/l) 6.1~9.6 ⇒ 7.5~  transparency ⇒ 2.5~3m
Tahara	easy to introduce outer sea water	「resort developing」  (bathing)  bathing, pond		790 / 220	COD (mg/l) 4~ ⇒ 2.7~3.6  DO (mg/l) ~4 ⇒ 6.5~7  transparency ⇒ 2~2.5m

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THE PROBLEM OF DIOXIN CONTAMINATION IN SEDIMENTS OF THE PORT  
OF NEW YORK AND NEW JERSEY

AD-P006 463



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INTRODUCTION

The subject of this paper is the problem of dioxin contamination in sediments of the Port of New York and New Jersey. The term dioxin describes an entire family of chlorinated hydrocarbon compounds. Figure 1 shows the most problematic form of dioxin, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). When "dioxin" is referred to in this paper, it is this specific compound. It is a highly toxic chemical often formed as a by-product during the manufacture of herbicides, wood preservatives, and other chlorinated hydrocarbon compounds. Also, it can be formed during paper bleaching processes or due to incomplete pyrolysis of fossil fuels or municipal wastes. Dioxin is extremely insoluble in water and shows a strong affinity to particulate matter, especially organic matter or fine-grained organic-rich sediments. Exceptionally low doses, in the parts per trillion range, have shown a wide range of toxic responses in laboratory test animals including carcinogenicity, teratogenicity, fetotoxicity, reproductive dysfunction, and immunotoxicity.

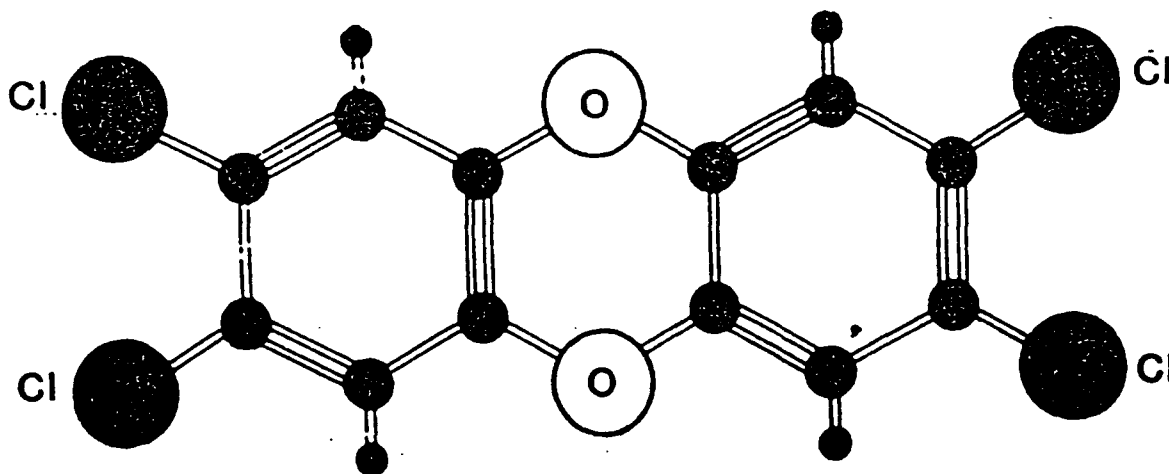


Figure 1. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)

NAVIGATION IN NEW YORK HARBOR

Before the problem of dioxin in the Port of New York and New Jersey can be discussed, it is useful to understand something about the Corps of Engineers' role in the Port. The New York District of the Corps of Engineers is responsible for maintaining adequate navigable depths in the more than 240 miles of Federal channels in the Port. This maintenance work requires dredging of approximately 5 to 7 million cu yd of mostly fine-grained

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sediments (muds) from these channels. Most of the dredging is accomplished by mechanical means, usually clamshell dredging. The sediments are loaded onto dump scows, and the scows are transported by tugboats to an offshore dump site. When the site is reached, doors in the bottom of the scow open up and deposit the sediment on the bottom of the sea. Since the early 1900's, harbor muds from the Port of New York and New Jersey have been dumped in the same general location approximately 6 miles offshore. This site is called the Mud Dump Site.

To determine if dredged material is environmentally suitable for ocean disposal, US Federal Law requires that the sediment undergo rigorous bioassay and bioaccumulation testing. Whenever there is good reason to believe that the sediment contains significant levels of contaminants, it is tested. Benthic marine animals, such as shrimp, clams, and worms, are placed in samples of the dredged material to be tested. Swimming marine animals, such as fin-fish and brine shrimp, are also subjected to the liquid and suspended particulate phases of the dredged material. These animals are monitored for a given period of time to determine the levels of acute toxicity of the dredged material. Animals still alive after the exposure period are analyzed to determine if bioaccumulation of contaminants of concern has occurred, and if so, the levels of the bioaccumulation. These test results are compared to preestablished ocean disposal criteria to determine suitability for ocean disposal.

It is with this understanding of the nature of the dredged material and management of dredged material disposal practices from the Port of New York and New Jersey that dioxin can now be discussed.

#### DIAMOND SHAMROCK COMPANY

Located in the northwest corner of the Port is a highly industrialized waterway known as the Passaic River. On this waterway is the site of a former herbicide plant known as the Diamond-Shamrock Company (Figure 2). During the 1960's this plant produced 2,4,5-T, which is one of the active ingredients in the defoliant known as "agent orange," widely used during the Vietnam War. Dioxin was produced as a by-product during the chemical processing of 2,4,5-T, and huge quantities of dioxin-laden processing water were discharged into the river. Over the years, dioxin concentrated in the sediments.

Only several miles downstream from this plant in Newark Bay are the Ports of Newark and Elizabeth, one of the largest container port complexes in the Western Hemisphere. In the mid-1980's the State of New Jersey Department of Environmental Protection documented that certain commercially valuable species of fish and shellfish in Newark Bay, New York Harbor, and the nearby portions of the ocean contained measurable levels of dioxin in their tissue. In several cases, the levels exceeded US Food and Drug Administration (FDA) levels of concern of 25 to 50 parts per trillion (ppt). Concern was raised that dioxin contamination was spreading to other adjacent waterways, including Newark Bay.

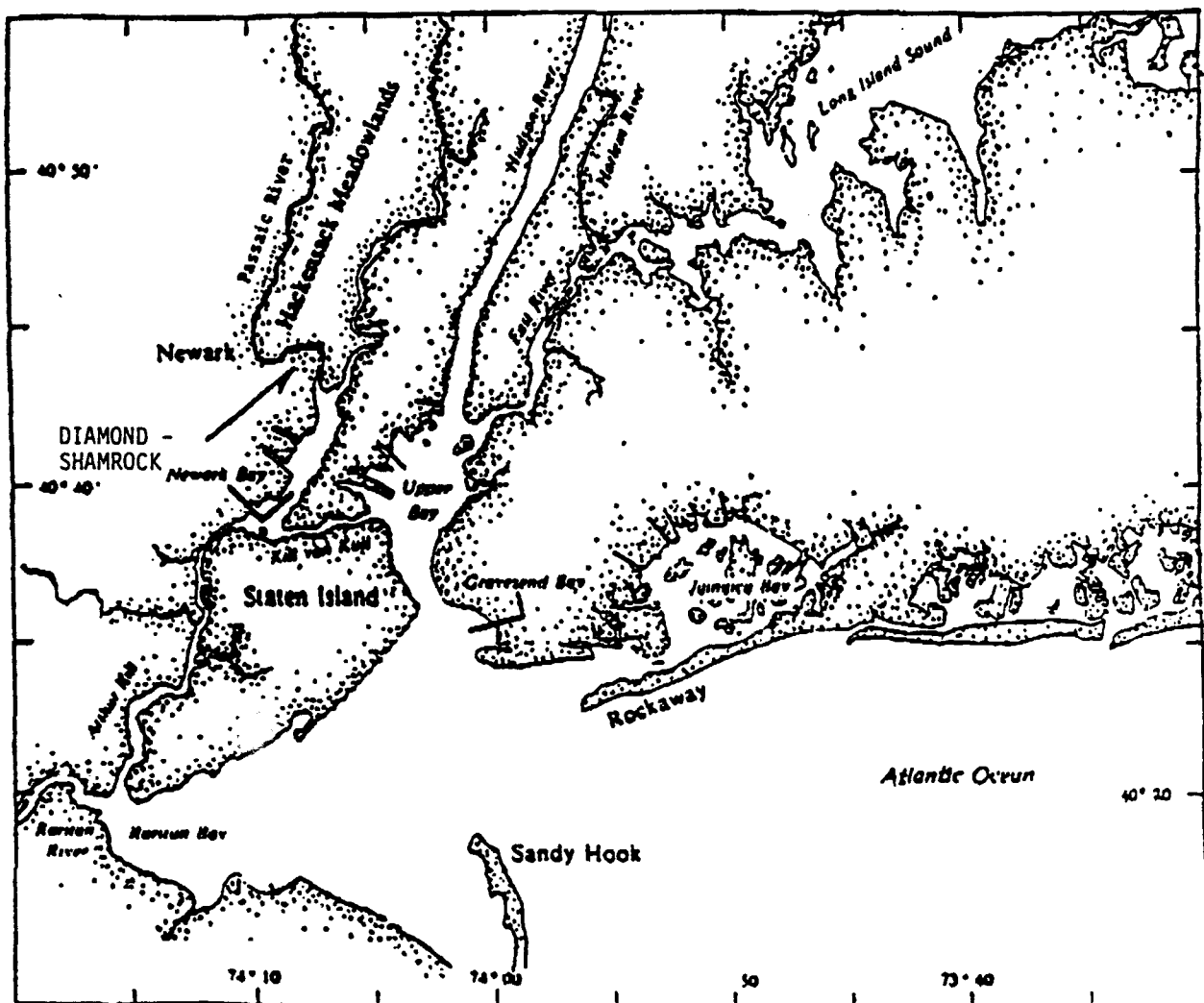


Figure 2. Diamond-Shamrock Company on Passaic River

#### KILL VAN KULL/NEWARK BAY DEEPENING PROJECT

This issue was brought to a head when plans to deepen the Federal navigation channels that lead to the Ports of Newark and Elizabeth became a reality (Figure 3). Environmental regulatory agencies were all concerned that dioxin might be present in the dredged material in levels that could cause harm to the ocean environment. The problem with addressing this concern was that no one could tell what any level of bioaccumulation of dioxin meant in marine animals. There was no clinical toxicological information available on the effects of dioxin bioaccumulation in the ocean environment. Also, at the time, it was not even possible to routinely test sediments for dioxin in the parts per trillion range. In short, the knowledge or the technology was not available to us to be able to evaluate the impacts of dioxin contamination in sediments to the marine environment.

In order not to delay such an important dredging project for the Port, another approach to the problem was taken. It was decided not to focus on

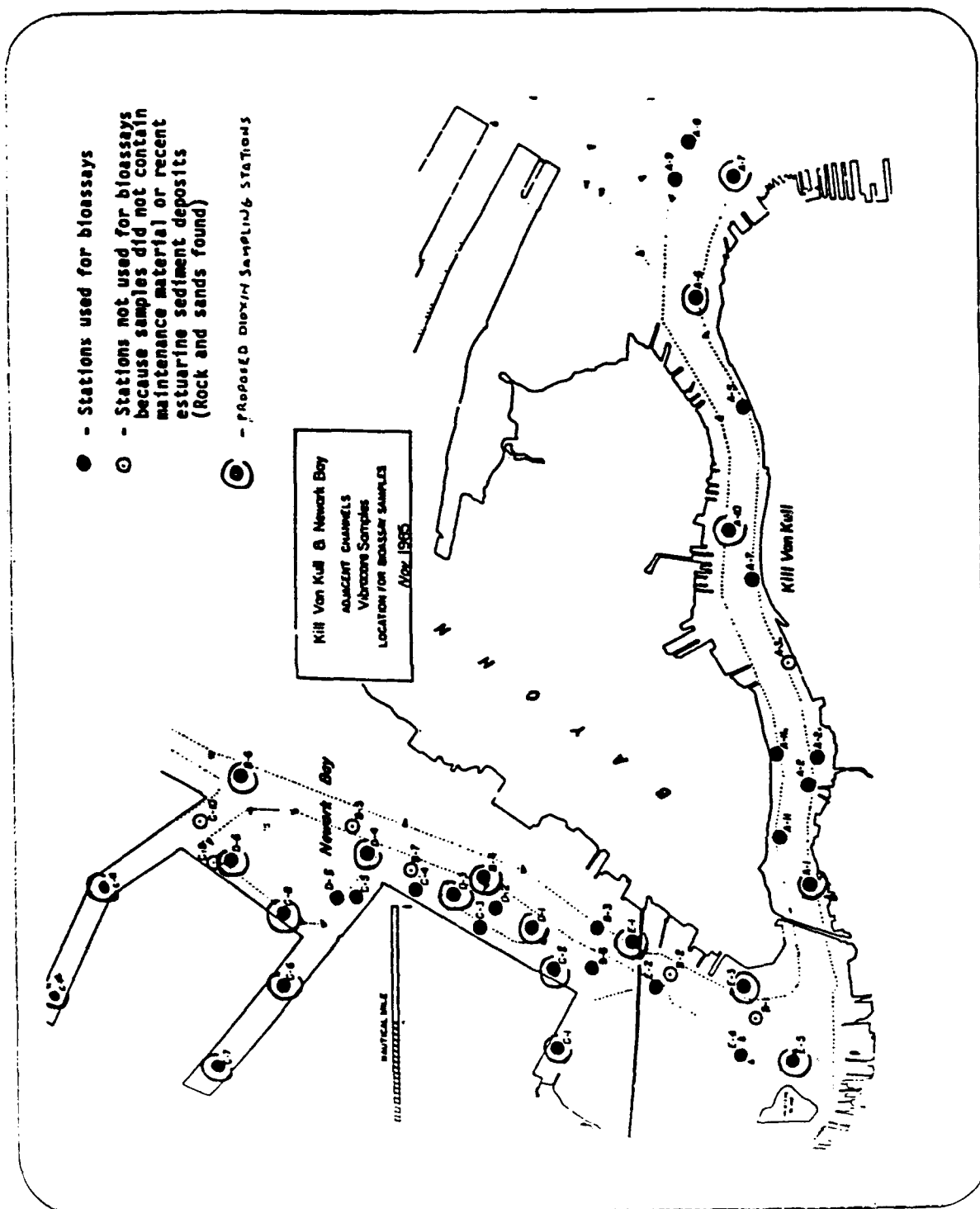


Figure 3. Kill van Kull/Newark Bay sampling sites

evaluating test results to determine the potential environmental impacts but instead on disposal management techniques that would isolate the sediment from the marine environment. Separate disposal areas were delineated at the Mud Dump Site for the sediment from the deepening project and for the normal day-to-day dredged material. This way the potential problem sediment was separated (Figure 4).

When the deepening project is completed, the dredged material is covered with a thick layer of clean dredged material to isolate the potentially contaminated sediment mound and prevent it from coming in contact with marine burrowing animals. The process of covering dredged material mounds is a dredged material management technique called capping. This technique has been the topic of several previous papers presented by my colleagues at past US/Japan Technical Experts Meetings.

Our experiences with the deepening project made us realize the importance of learning more about dioxin. The problem was not going to go away. In fact, the scope of the dioxin area appeared to be growing beyond the Newark Bay drainage area. The New York District Army Corps of Engineers took the lead, since it was the dredging program that was the catalyst for the need for information. First, an Interagency Dioxin Committee composed of the involved regulatory agencies was formed. The committee includes representatives from each agency's regulatory compliance offices and their respective research laboratories. Besides the Corps of Engineers, the agencies on the committee are the US Environmental Protection Agency, US Fish and Wildlife Service, National Marine Fisheries Service, and New Jersey Department of Environmental Protection.

### THREE-TIERED DIOXIN TESTING FRAMEWORK

The first task of the committee was to agree to a logical dioxin testing and evaluative framework. The New York District proposed a three-tiered testing framework (Figure 5). If there is a reason to believe that dioxin is present, Tier 1 would involve testing the sediment for dioxin at a detection level of 1 ppb. When the deepening project was being evaluated a few years ago, it was not possible to achieve a detection limit of 1 ppb in sediments. Because of recent state-of-the-art improvements in analytic techniques, these detection limits can now be achieved. If dioxin is not present, no further evaluation is needed. If it is present, a Tier 2 analysis is done.

In Tier 2, dioxin and total organic carbon concentrations in sediments would be used in conjunction with a thermodynamic method of predicting the maximum tissue bioaccumulation potential. The thermodynamic method involves calculating the quantity of dioxin available for bioaccumulation as a function of the relationship between total organic carbon and dioxin content in the sediment and the lipid (fatty tissue) content in benthic marine species that could come in contact with the sediment. Increasing total organic carbon content in the sediment tends to decrease the bioavailability of dioxin, and increasing lipid content in target animals tends to increase bioaccumulation potential. The thermodynamic calculation balances the competition for dioxin between sediment organic content and animal lipid content. It is an extremely conservative approach and generally overestimates bioaccumulation levels. However, it is for this very reason that it makes an excellent screening tool to determine if real-time bioaccumulation testing is necessary on a

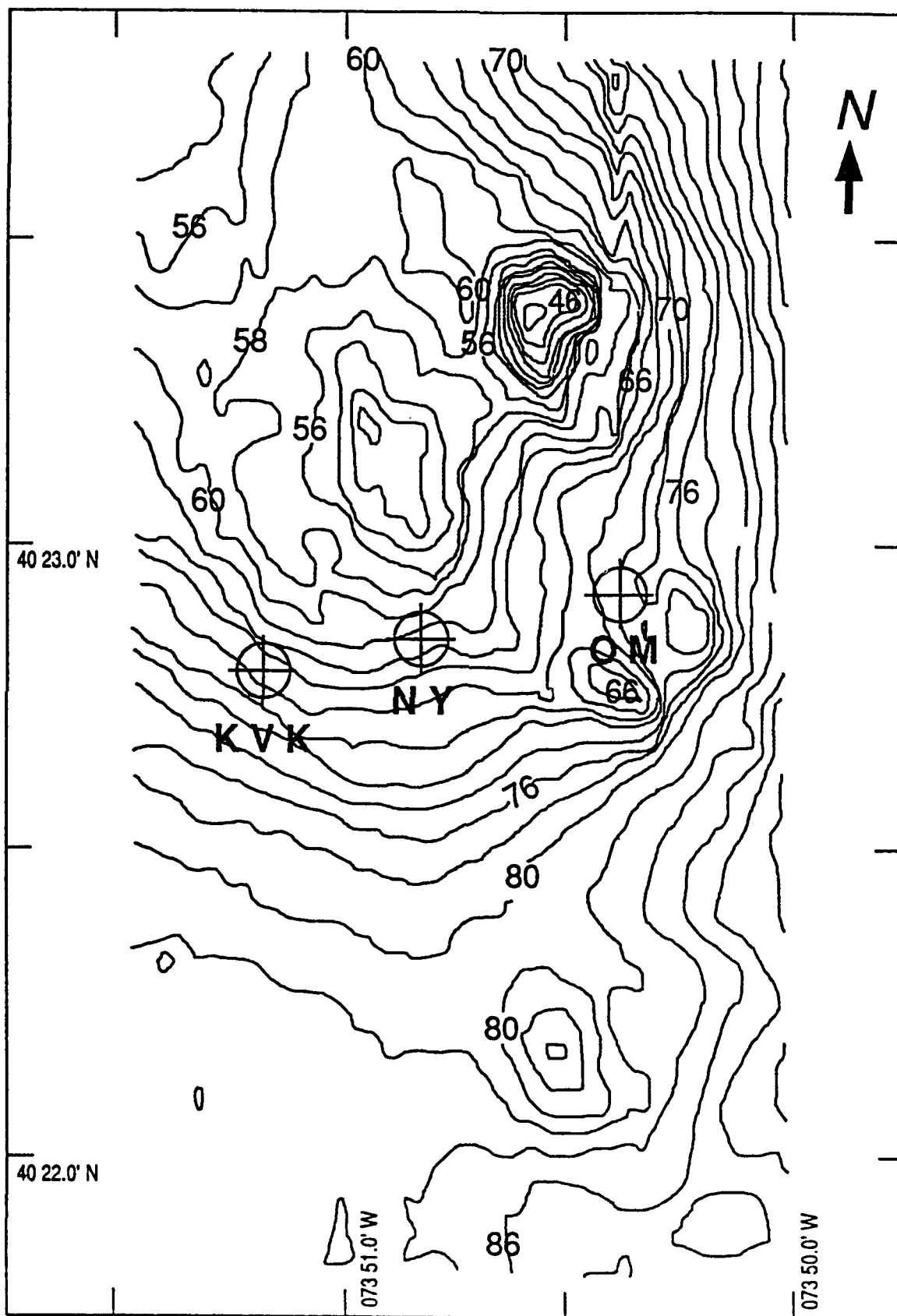


Figure 4. Mud Dump Site

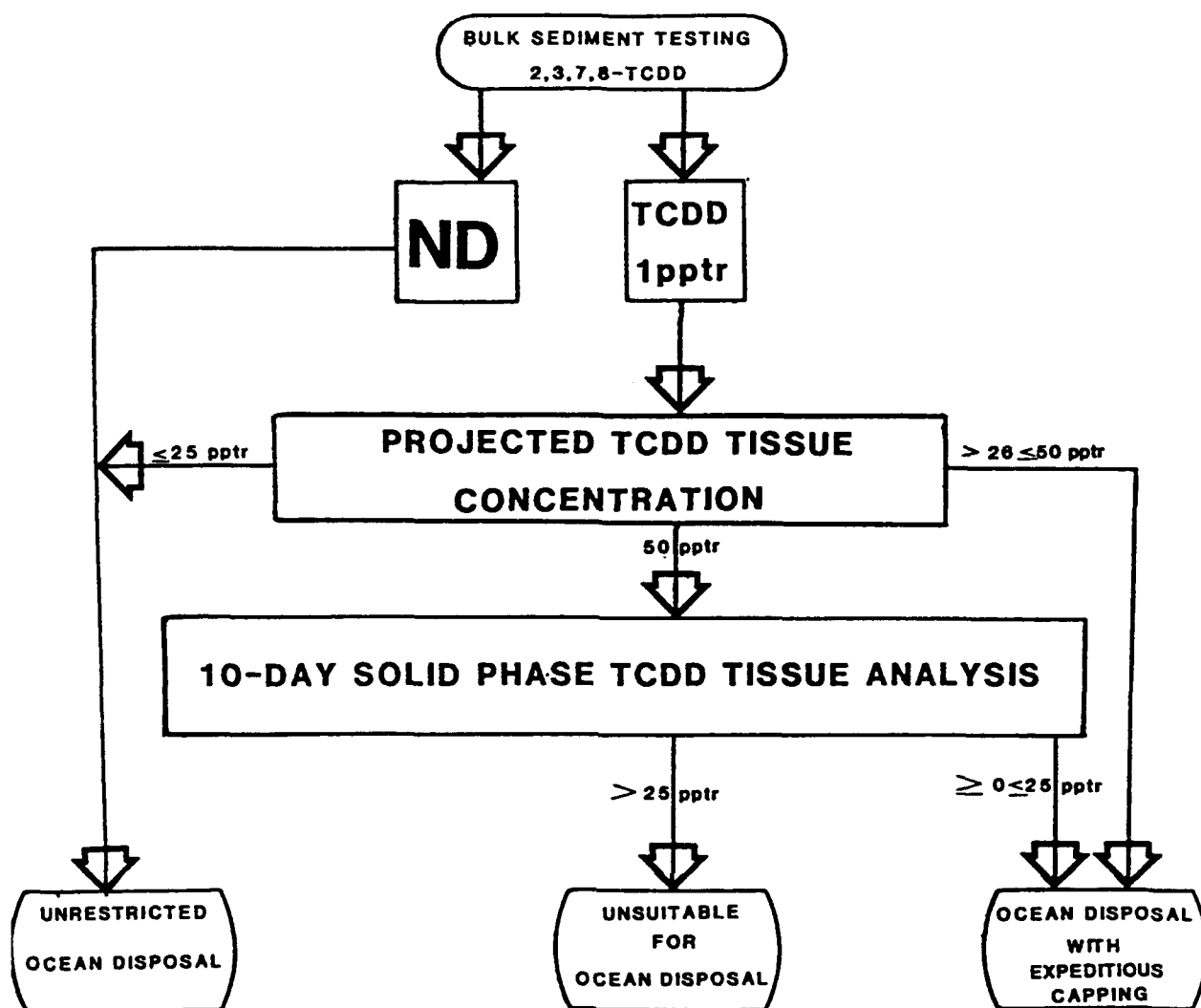


Figure 5. Interim three-tier 2,3,7,8-TCDD testing approach

case-by-case basis. Since bioaccumulation factors were not yet derived for dioxin, the factors developed for PCBs were used in the thermodynamic equations proposed for Tier 2. It was assumed that uptake behavior would be similar since the two contaminants were chemically similar.

In Tier 2, the original proposal used evaluative criteria based on FDA tissue levels of concern to interpret projected tissue levels of dioxin. The FDA criteria are as follows:

- a. For levels in fish below 25 pptr--little cause for concern.
- b. For levels in fish between 25 and 50 pptr--restriction of intake to no more than one meal of fish per week.
- c. For levels exceeding 50 pptr--the State should consider a ban on the consumption of fish from these areas.

These criteria were transposed to an ocean disposal management framework:

- a. For all calculated tissue levels at 25 pptr or below, unrestricted ocean disposal will be allowed.
- b. For all calculated tissue levels between 26 and 50 pptr, only ocean disposal with expeditious capping will be allowed.
- c. For all calculated tissue levels above 50 pptr, proceed to a Tier 3 analysis.

In Tier 3, a 10-day solid phase bioassay/bioaccumulation analysis for dioxin would be performed using a representative species for the environs of the Mud Dump Site, the sandworm *Nereis virens*. For Tier 3, 25 pptr was proposed as the cutoff point. An average tissue concentration of less than 25 pptr in Tier 3 would be determined suitable for ocean disposal with expeditious capping. Any averaged tissue concentration greater than 25 pptr would be unsuitable for ocean disposal at the present time.

The concept of this tiered approach was for the most part accepted among the committee. The problems in implementing it revolved around three questions:

- a. Are the thermodynamic relationships expected in the Tier 2 calculations really true?
- b. Will a 10-day bioaccumulation test be long enough to adequately reflect steady-state bioaccumulation potential?
- c. Is it realistic to use dioxin levels as high as 25 and 50 pptr as decision levels in Tier 2 or Tier 3?

The bottom line was that no laboratory data were available on bioaccumulation of dioxin upon which to base a realistic bioaccumulation test or thermodynamic calculation. Also, there were no field data on levels of dioxin occurring in benthic marine species in the nearshore ocean that could be used as the basis for bioaccumulation criteria.

#### DIOXIN BIOACCUMULATION STUDIES

To address these questions, two studies were initiated. The first was designed to address the questions concerning the length of the bioaccumulation test period and the validity of the Tier 2 thermodynamic calculations. Specially designed tanks were used for long-term exposure of selected marine species to sediment contaminated with dioxin. The objectives of the study were to determine the bioavailability of dioxin from contaminated sediments, measure the time required for tissue concentrations to reach steady state, measure depuration rates, and evaluate the bioaccumulation factors needed for developing a technically valid Tier 2 thermodynamic calculation.

The second study was designed to address the question concerning appropriateness of using dioxin tissue levels of 25 and 50 pptr as decision levels. It was determined that the best way to address this question was to conduct a

survey of ambient tissue levels of benthic marine animals in the general environs of the Mud Dump Site. The average amount of dioxin in the tissue of animals that could come in contact with the dredged material would be used as a point of comparison with the test results. If the dredged material testing determines that the levels of bioaccumulation are less than the ambient dioxin levels determined by the survey, then the dredged material may be acceptable for ocean disposal.

#### DISCUSSION OF RESULTS

Although both studies have not yet been completed, there is enough information to make several conclusions. Figure 6 illustrates the most important facts. Shown is the concentration of dioxin uptake in tissue (dry weight) plotted against number of days of exposure to the contaminated sediment. Three species were exposed: *Nereis virens* (sandworm), *Macoma nasuta* (clam), and *Palaemonetes pugio* (grass shrimp). Also shown by the dotted lines is depuration of dioxin from subsets of the clam and worm populations that were taken out of the exposure tanks on day 84. The total exposure periods for the worms and clams were 180 and 120 days, respectively. The grass shrimp was exposed for only 28 days. None of the animals was fed during the exposure periods in order not to introduce additional "unknowns" into the experiment. The grass shrimp could not survive more than 28 days under those conditions.

The uptake curves for the worms and clams show that although uptake of dioxin is slow, both species reach a steady-state concentration eventually. For the worm, steady state appears to be achieved between day 70 and day 120, and for the clam, between day 28 and day 42. Before this experiment, no one knew whether steady-state concentrations were ever reached. Previous dioxin bioaccumulation studies in freshwater systems did not show that steady state was ever achieved. These curves also show that most of the total bioaccumulation in the clams and half the total bioaccumulation in the worms occur in the first 28 days of exposure. Thus, it is concluded that a 10-day solid phase bioaccumulation test is not adequate. Exposures of at least 28 days are needed for a meaningful test.

Another important conclusion can be inferred by observing the depuration rates. The clams lost almost their entire body burden of dioxin within 42 days of being removed from the contaminated sediment. The worms are slower in depuration, but they still lost half their body burden during the remainder of the experiment, with no change in the downward trend. These changes show that dioxin contamination in animals is reversible once exposure to the contaminant is eliminated and that isolating the animals from exposure to dredged material, as is done when capping, is adequate to minimize the impacts from dioxin contamination.

This uptake curve also gives us the information necessary to develop a realistic thermodynamic equilibrium equation that can be used in a Tier 2 analysis. Before this curve was determined, it was assumed that dioxin bioaccumulation factors could be modeled after bioaccumulation factors already experimentally derived for PCBs. This experiment confirmed our hypothesis that PCBs were a reasonable model to follow, and a thermodynamic equation for dioxin uptake can now be derived.

# 2,3,7,8-TCDD

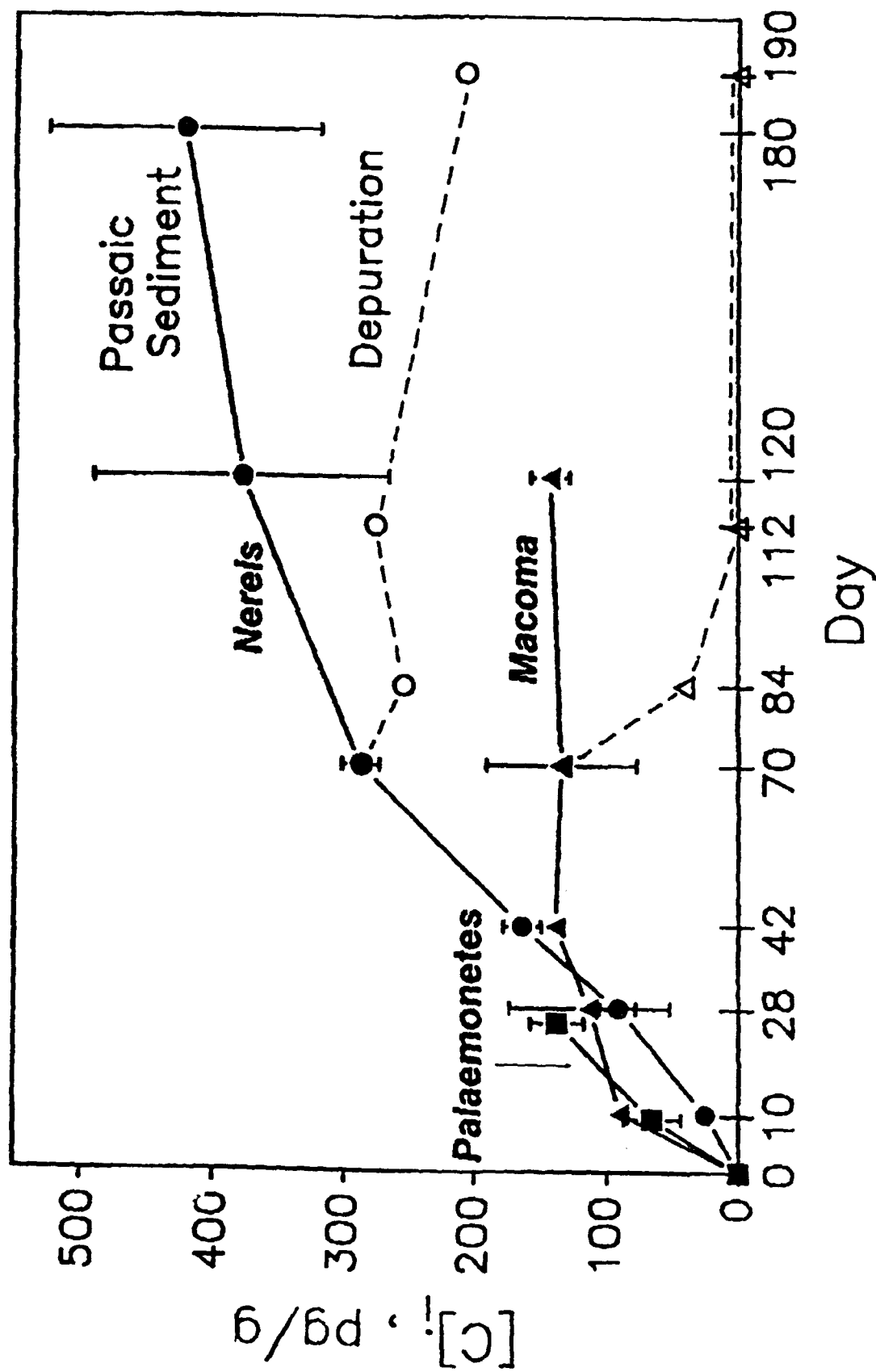


Figure 6. Dioxin uptake against days of exposure to contamination by the species *Nereis*, *Macoma*, and *Palaemonetes*

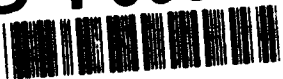
Finally, concerning the survey of ambient tissue levels in the general environs of the disposal site, data are still being evaluated. However, preliminary indications are that there is an average ambient level of dioxin in benthic infaunal species of approximately 4 pptr. Perhaps this level of bioaccumulation could be used as a starting point for discussions when determining if dredged material is suitable for ocean disposal.

#### CONCLUSIONS

In conclusion, some headway has been made in obtaining the knowledge necessary to evaluate the potential ecological impacts of ocean disposal of dredged material that is contaminated with dioxin, as summarized below:

- a. Dioxin reaches steady-state concentrations in tissues of at least some marine species.
- b. A 28-day bioaccumulation test appears reasonable.
- c. Animals will depurate significant levels of their body burden of dioxin once exposure to contaminated sediment is ended. This implies that capping would work.
- d. Assumptions made concerning thermodynamic equilibrium models of bioaccumulation are shown to be accurate, and a reasonable model can be derived for dioxin.
- e. Finally, FDA levels of concern are probably too high to use as disposal criteria. Preliminary data indicate that 4 pptr may be a more realistic bioaccumulation level to use based on ambient levels of dioxin bioaccumulation in the environs of the disposal site.

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#### ABSTRACT

This paper describes a potential partial utilization of certain types of sludgy industrial waste, using a geotechnical engineering viewpoint. The primary objective is to investigate the potential for burning various industrial wastes combined with lime, in certain proportions, to produce a by-product having hardening characteristics similar to ordinary portland cement (OPC). The potential for using this new cement-like stabilizer (NCS) for stabilizing loam soil is then examined. It is found that the percentages of main cementitious compounds in NCS, except alite ( $C_3S$ ) compound, are higher than in OPC. The strength of soil increases about 2 to 10 times that of remolded unconfined compressive strength (i.e., 34.0 to 170.0 kN/m<sup>2</sup>) as the stabilizer content and curing time are increased. The by-product thus shows promise for use in stabilizing a loam soil for subgrade purposes. Results are discussed in relation to the contribution of ettringite in strength development.

#### INTRODUCTION

In recent years, researchers from various fields have attempted to solve environmental problems posed by the production of industrial wastes. Gidley and Sack (1984) suggested various methods of utilization of these wastes in construction. Studies have also been carried out to investigate the possibilities of using industrial wastes such as slag, fly ash, sludge ash, and crushed concrete powder in cement and concrete (Mehta 1985, Duda 1987, Tay 1987, Dhir et al. 1988, Kamon et al. 1988). Potential uses for this material include structural fill and subbase course for roads (Leonards and Bailey 1982, Kamon et al. 1988). Recent projects illustrated that successful waste utilization could result in considerable savings in construction costs (Morgan et al. 1984, Jefts 1986).

Incineration is another way to eliminate problems of disposal of sludgy waste materials containing oily and toxic materials. Chemical analyses have shown that many modern industrial waste sludges are rich in main oxides such as  $CaO$ ,  $Al_2O_3$  (alumina),  $SiO_2$ , and  $Fe_2O_3$  (ferrite). It is therefore of great

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benefit to the soil stabilization if this kind of waste can be converted into a useful material. The primary objective of this study is to examine the potential for burning various industrial wastes, of predetermined proportions, to give a by-product which has self-cementing characteristics similar to ordinary portland cement (OPC). The potential for using this cement-like material for stabilizing loam soil is then examined.

Experimentally, the approach used in this study consisted of X-ray diffraction (XRD) analysis and scanning electron microscope (SEM) observation to investigate the main chemical compounds of an anhydrous stabilizer and the reaction products produced in hydrated stabilizer and stabilized soil. Results of a laboratory investigation concerning the effectiveness of this new type of stabilizer in comparison with OPC are evaluated using a measure of the unconfined compressive strength ( $q_u$  strength), XRD analysis, and SEM observation.

## EXPERIMENTAL PROCEDURE

### Material

#### Manufacturing Process and Some Characteristics of a New Cement-Like Stabilizer

Producing stabilizers by combining industrial wastes was first reported by Shida et al. (1987). Following their study, a new cement-like stabilizer (hereafter refer to as NCS), derived mainly from various types of industrial wastes, was produced. The raw materials of this new stabilizer include sludges or cakes from a rubber factory (referred to as A factory), a sugar manufacturing plant (B factory), and a brewery (C factory), as well as slag from a steel manufacturing plant (D factory). All leachates complied with water quality standards established by the Japanese Environment Agency (see Appendix I), which permits their use as raw materials.

Two considerations are important in the preparation of raw materials for NCS production:

- a. Total amount of oxide.
- b. Self-cementing characteristic.

The total amount of the main oxides, predetermined by using various proportions of waste materials, is used for the evaluation of hydraulic properties.

The self-cementing characteristic is expressed in terms of the hydration modulus, which is defined as the ratio of CaO to the summation of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ . The hydration modulus is determined with reference to those of alite and belite cement compounds, whose chemical compositions and calculated hydration moduli are given in Table 1. As a target for material control, the hydration modulus should be within the range of 1.7 (approximately corresponding to belite) to 2.4 (approximately corresponding to alite). It is for this reason that CaO (in the form of lime) is added.

TABLE 1. CHEMICAL COMPOSITIONS OF CEMENT COMPOUNDS

Compound	Chemical Compositions (% by Dry Weight)						
	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	MgO	K <sub>2</sub> O
Alite	72.23	1.24	24.83	0.94	0.09	0.98	0.14
Belite	62.83	2.13	32.50	1.03	0.20	0.52	0.30

$$\text{Calculated Hydration Modulus of Alite} = \frac{72.23}{1.24 + 24.83 + 0.94} = 2.67$$

$$\text{Belite} = \frac{62.82}{2.13 + 32.50 + 1.03} = 1.76$$

The proportion of raw mixtures was assigned to be A:B:C:D:Lime = 5:60:10:5:20. The calculation of chemical compositions for the raw mixture is carried out by multiplying the percentage of main oxides illustrated in Table 2 with the predetermined proportion. Table 3 shows the total amount of each main oxide after combining, resulting in a hydration modulus of 1.78, which is in the range of target values.

After all raw materials had been oven-dried, they were crushed and weighed according to the predetermined proportion. The materials were blended and compounded, and then burned under oxidizing conditions. (The analysis of gas produced during burning was performed, but the generation of pollutants such as NO<sub>x</sub> and dioxins was not found.) The chemical reactions and new crystals produced were dependent on a burning temperature, as highlighted in Table 4. The resultant burned clinker was rapidly cooled in cooling water, then sprayed with -50° C gas until the temperature was lowered to about 100° C. Then it was removed from 100° C environment and allowed to cool to room temperature. The clinker was ground into powder having particle size smaller than 0.075 mm and blended with gypsum to produce a hardening material similar to OPC.

When compared with cement, NCS has a higher specific surface area but smaller specific gravity: 4,090 and 3,350 cm<sup>2</sup>/g, and 3.07 and 3.17, respectively. The chemical compounds in NCS and OPC are given in Table 5. It was found that the percentages of main cementitious compounds in NCS, except C<sub>3</sub>S grain, are higher than in OPC.

As shown in Figure 1, the X-ray diffraction patterns for anhydrous and hydrated NCS exhibit significant reductions of the 7.3 Å C<sub>2</sub>S (dicalcium silicate), 4.9 Å C<sub>2</sub>S, 3.5 Å C<sub>3</sub>S (tricalcium silicate), and 2.7 Å C<sub>3</sub>A (tricalcium aluminate) peaks, and show increases of 9.7 Å and 5.6 Å ettringite peaks, as well as the 3.00 to 3.02 Å calcium silicate hydrate peaks, after having been hydrated for 3 days. Observation by SEM supports the results by XRD.

TABLE 2. CHEMICAL COMPOSITIONS OF INDUSTRIAL WASTES BY QUANTITATIVE ANALYSIS

Material*	Chemical Composition (% by Dry Weight)																	
	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	MgO	K <sub>2</sub> O	TiO	V <sub>2</sub> O <sub>5</sub>	Cr <sub>2</sub> O <sub>3</sub>	MnO	CuO	NiO	ZnO	BaO	PbO	Ignition loss	Total
A	6.72	36.84	38.29	1.36	1.09	0.48	1.44	0.42	<0.01	0.23	0.013	<0.01	<0.01	-	1.00	<0.01	11.6	99.52
B	37.36	2.27	11.77	0.37	0.62	0.61	0.79	-	-	-	0.025	<0.01	-	<0.01	-	-	45.0	98.81
C	0.38	3.2	82.50	0.79	1.6	-	0.67	-	-	-	-	-	-	-	-	-	9.26	98.40
D	0.34	0.11	0.40	59.3	7.71	0.015	0.02	0.01	-	0.02	0.04	0.01	0.02	0.09	-	0.09	30.6	99.13

\* A = rubber factory sludge.  
 B = sugar manufacturing plant sludge.  
 C = brewery sludge.  
 D = iron rust slag.

TABLE 3. CALCULATION OF CHEMICAL COMPOSITIONS FOR RAW MIXTURE

Material	Chemical Compositions (% by Dry Weight)					
	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	MgO
A	0.336 (6.72 × 0.05)	1.842 (36.84 × 0.05)	1.915 (38.29 × 0.05)	0.068 (1.36 × 0.05)	0.055 (1.09 × 0.05)	0.024 (0.48 × 0.05)
B	22.416 (37.36 × 0.60)	1.362 (2.27 × 0.60)	7.062 (11.77 × 0.60)	0.222 (0.37 × 0.60)	0.372 (0.62 × 0.60)	0.366 (0.61 × 0.60)
C	0.038 (0.38 × 0.10)	0.32 (3.2 × 0.10)	8.25 (82.50 × 0.10)	0.079 (0.79 × 0.10)	0.16 (1.6 × 0.10)	-
D	0.017 (0.34 × 0.05)	0.006 (0.11 × 0.05)	0.002 (0.40 × 0.05)	2.965 (59.3 × 0.05)	0.386 (7.71 × 0.05)	0.001 (0.015 × 0.05)
Lime	20.00	-	-	-	-	-
Total (%)	42.81	3.53	17.23	3.34	0.97	0.39

Note: Proportion of raw mixture is A:B:C:D:Lime = 5:60:10:5:20.

$$\text{Calculated Hydration Modulus} = \frac{42.8}{3.53 + 17.23 + 3.34} = 1.78$$

TABLE 4. CHEMICAL REACTIONS AND THERMAL CONVERSION PRODUCTS  
CORRESPONDING TO EACH BURNING TEMPERATURE

Burning Conditions	Temperature (°C)	Chemical Reaction Corresponding to Burning Temperature
After igniting, the temperature is increased to 800° C over a period of 6 hr.	100 - 110	Evaporation adsorbed water of sludges
	450 - 800	Decomposition of sludges associated with diffusion of crystal water, resulting in weakening of SiO <sub>2</sub> and Al <sub>2</sub> O <sub>3</sub> bonds
After holding the temperature at 800° C for 2 hr, it is increased to 1,200° C.	900 - 1,000	Beginning to form 2CaO • 7Al <sub>2</sub> O <sub>3</sub> compound
	1,000 - 1,200	Forming 2CaO • SiO <sub>2</sub> • Fe <sub>2</sub> O <sub>3</sub> compound
After holding the temperature at 1,200° C for 2 to 4 hr, it is increased to 1,500° C and held for 2 hr.	1,200 - 1,350	Forming 3CaO • Al <sub>2</sub> O <sub>3</sub> and 4CaO • Al <sub>2</sub> O <sub>3</sub> (clinker formation)
	1,350 - 1,500	Forming 3CaO • SiO <sub>2</sub> and the clinkers have been completely melted
	Cool immediately	Will prevent a conversion of α2CaO • SiO <sub>2</sub> to γ formation

TABLE 5. CHEMICAL COMPOUNDS IN STABILIZERS

Stabilizer	Chemical Compound (X)*				
	C <sub>2</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> AF	CaSO <sub>4</sub>
NCS	19.6	35.3	27.1	6.80	6.30
OPC	63.2	12.9	11.6	4.00	3.30

\* The following cement chemistry notations are used: C = CaO, A = Al<sub>2</sub>O<sub>3</sub>, F = Fe<sub>2</sub>O<sub>3</sub>, and S = SiO<sub>2</sub>.

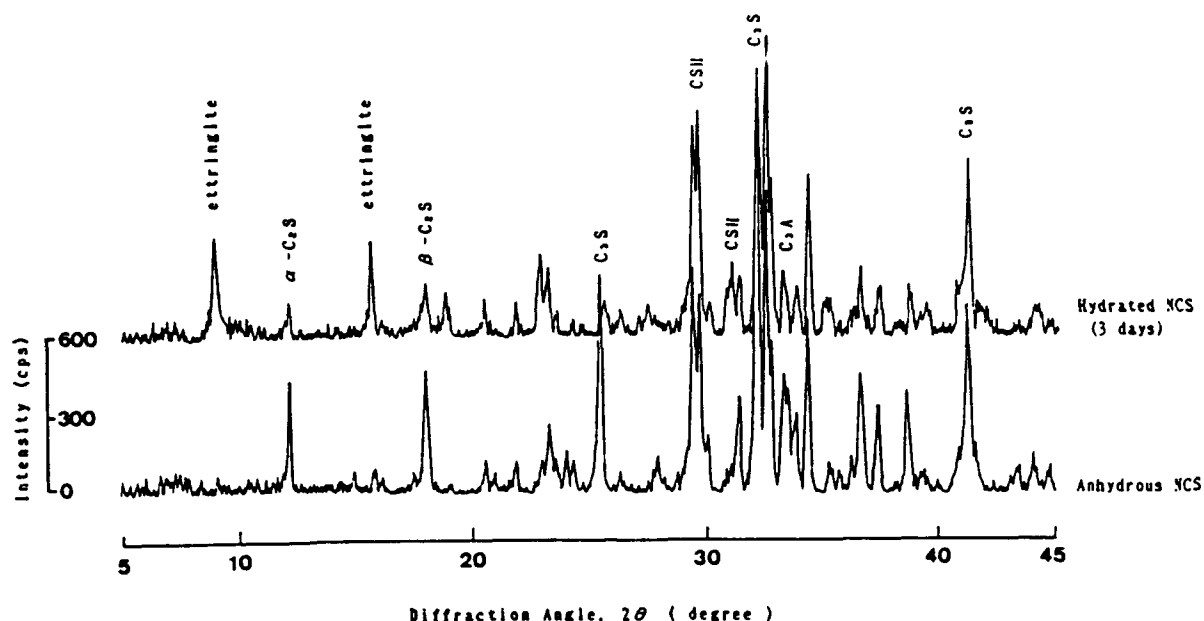


Figure 1. X-ray diffraction patterns for anhydrous and hydrated NCS

Figure 2 shows significant changes in mineralogical phases of NCS when mixed with water ( $w/c = 0.5$ ) and cured for 3 days. It can be noted that large  $C_3S$  and  $C_2S$  grains disappeared, whereas ettringite abundantly covered the surfaces.

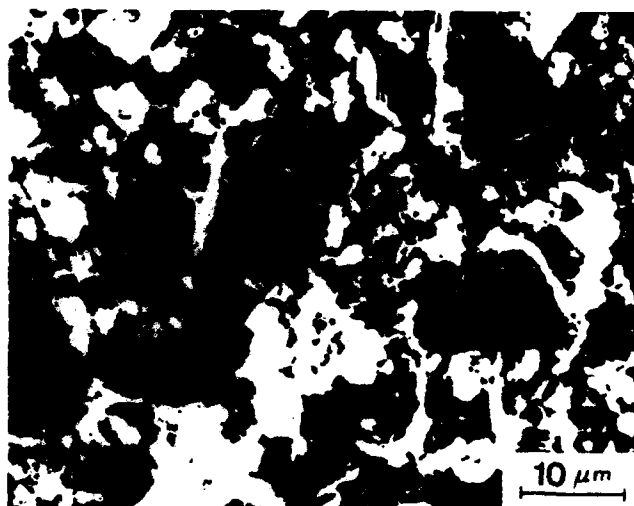
#### Soil Material

Volcanic ash soils or loam soils are regional soils in Japan, widely distributed over about half of the country. They possess certain characteristics causing some construction problems. Owing to the presence of a high moisture content and organic matter (ignition loss = 11.6 percent), the strength is considerably decreased when disturbed. The average remolded  $q_u$  strength is  $20 \text{ kN/m}^2$ .

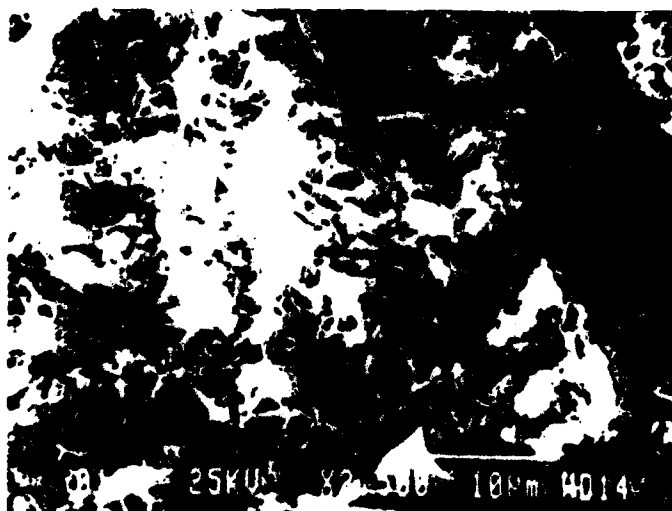
Upon visual examination, the soil has a yellow-brown color and contains small amounts of fibrous root-plants. This soil forms individual clusters of various sizes when desiccated. Results obtained from XRD analysis show that relatively high intensities are reflexed corresponding to peaks of quartz and feldspar regarded as primary minerals. In addition, chlorite mineral is also found as well as some amorphous materials. Further data on physical properties of the soil are given in Table 6.

#### Specimen Preparation and Tests

Specimens were prepared by mixing loam soil with a natural moisture content and two types of stabilizer, NCS and OPC. The mix proportions were 3, 6, 9, and 12 percent by bulk weight. In accordance with the Japanese Society of Soil Mechanic and Foundation Engineering guidelines, the following procedure was used. Cylindrical molds measuring 5 cm in diameter by 10 cm in length were used. After mixing, the soils were placed in molds in three layers.



a. Angular with fine to medium crystallines (10-40  $\mu\text{m}$ ) of  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$ , and  $\text{C}_3\text{A}$  and gypsum before hydration



b. Growth of ettringite and CSH on surface after hydration for 3 days

Figure 2. Changes in mineralogical phases of NCS

TABLE 6. PHYSICAL PROPERTIES OF LOAM SOIL

Sand fraction (2-0.075 mm, %)	25.2
Silt fraction (0.075-0.005 mm, %)	61.7
Clay fraction (less than 0.005 mm, %)	13.1
*60% finer ( $D_{60}$ , mm)	0.0275
Coefficient of conformity ( $U_c$ )	6.60
Coefficient of concavity ( $U'_c$ )	1.53
Natural moisture content ( $W_n$ , %)	86.4-90.0
Liquid limit (LL, %)	129.0
**Plastic limit (PL, %)	75.2
Plasticity Index (PI)	53.8
Specific gravity ( $G_s$ )	2.87
Ignition loss (%)	11.6

\* Grain-size analysis.

\*\* Consistency test.

Each layer was confined with a confining plate using static kneading energy to reduce relatively large air voids. After molding, the specimens were weighed to an accuracy of 5 g to confirm that the density was uniform at the beginning stage. After approximately 18 to 24 hr, the molds were removed and the specimens were sealed by wrapping them tightly with thin plastic sheets, followed by aluminum foil, to prevent loss of moisture due to surface evaporation. Finally, for each sample proportion, specimens were cured at a room temperature of  $20^\circ \pm 2^\circ \text{C}$  and 80 percent relative humidity for periods of 3, 7, 28, and 90 days, respectively. The specimens were subjected to the strength test after the specified number of days.

The strengths were determined by an unconfined compression test using the strained-controlled method at a constant rate of deformation of 1.0 mm/min. Moisture content was measured just after the initial mixing, and after testing, by placing the soils in the oven at a drying temperature of  $110^\circ \pm 5^\circ \text{C}$  for one night. Failures were also tested with a Rigaku X-ray diffractometer (using a Cu-target with a Ni-filter and input energy of 40 kV and 20 mA) and a JSM-840 scanning electron microscope to identify reaction products and to observe changes of the internal structure in the soil after treatment.

## RESULTS AND DISCUSSION

The development of soil strength when stabilized with NCS and OPC is shown in Figure 3. It can be noted that the strength increases about 2 to 10 times the remolded  $q_u$  strength (i.e., 34.0 to 170.0 kN/m<sup>2</sup>), as the stabilizer content and curing time are increased. In both mixtures the strength does not change significantly at the low mix proportion (i.e., lower than 6 percent). It can be clearly seen that the strength gained when NCS is used is about 1.5 times that gained when OPC is used at a mix proportion of 12 percent. Based on the results obtained, stabilized loam soil appears satisfactory for subgrade stabilization.

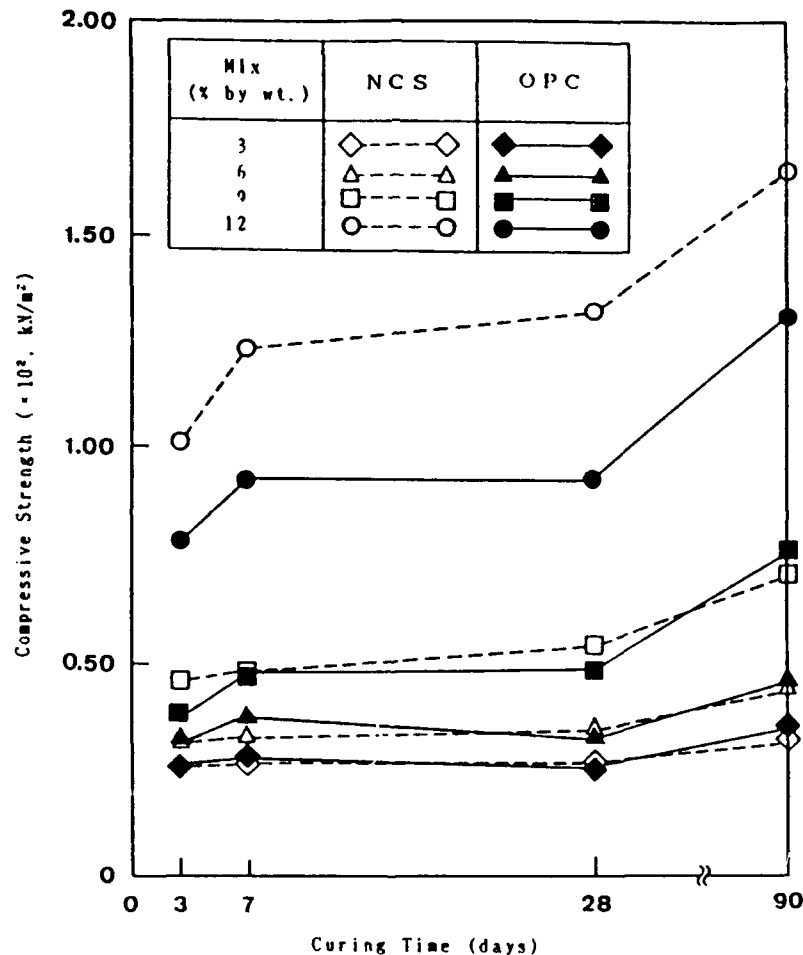


Figure 3. Comparison of strengths obtained when loam soil is stabilized with NCS and OPC (values represent the average  $q_u$  strength of two specimens)

When results obtained from the strength test are compared to with those from the XRD and SEM investigation, the addition of relatively small amounts of stabilizers shows no noticeable changes. For this reason, it is most likely that the reactions proceed at a slow rate. The development of strength in this case is attributed to an agglomeration caused by the exchange of  $\text{Ca}^{++}$ ,  $\text{N}^+$ , and  $\text{H}^+$  ions.

In the presence of a greater quantity of cementitious compounds, the reactions proceed more rapidly. This fact can be confirmed by investigating X-ray diffraction patterns (Figure 4). The reaction products are identified with a higher degree of crystallinity. Ettringite diffracted by X-ray at 9.7 Å and 5.6 Å are well defined at the initial stage of reaction. However, a slight reduction in the intensities are noted after several months. The peaks for calcium silicate hydrate (CSH) detected at 3.00 to 3.02 Å are also apparent, while those anhydrous cementitious minerals gradually disappear after further curing.

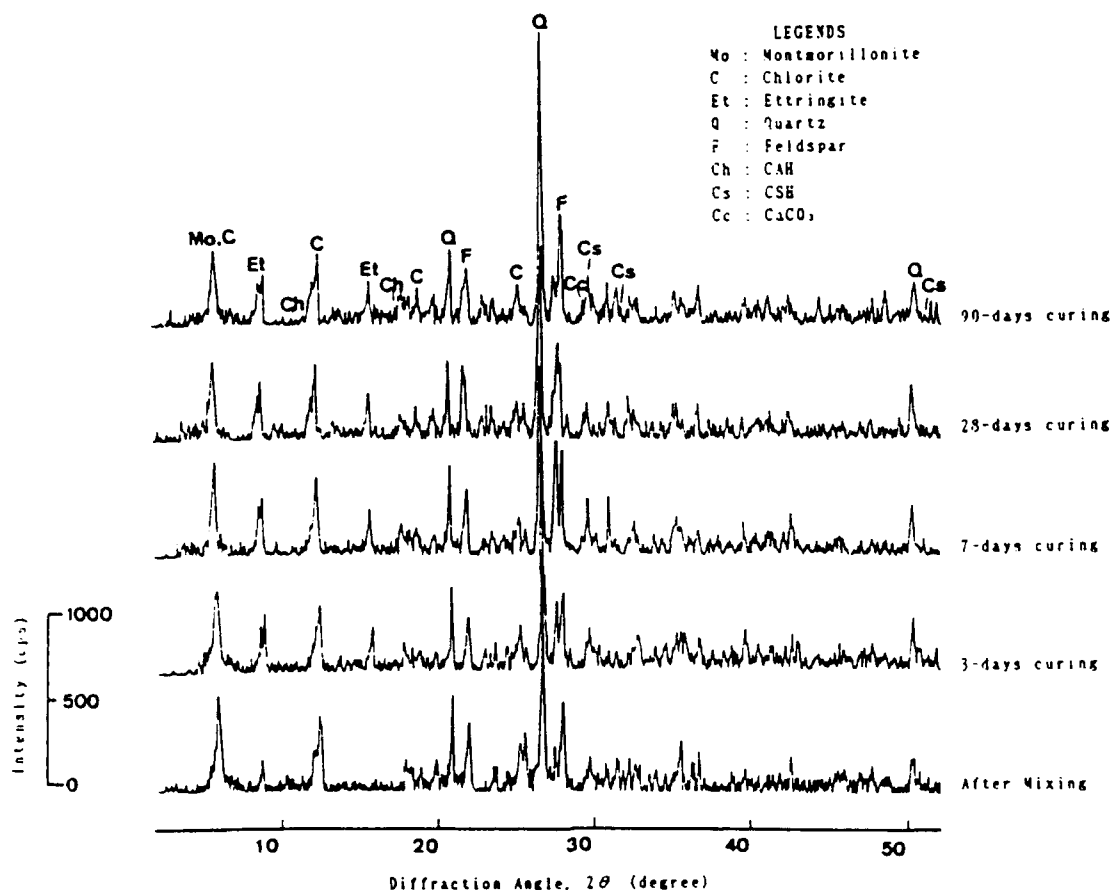


Figure 4. X-ray diffraction patterns for loam soil after mixing, and for mixtures containing 12 percent NCS aged for 3, 7, 28, and 90 days

The electron micrographs of loam stabilized with 12 percent NCS, observed at 90 days, are shown in Figure 5. It can be seen that the needle-like crystals of hardened ettringite intercross between soil particles and surfaces, filling up the spaces which, it is assumed, were previously filled with pore water. Mehta (1983) found that ettringite of this form, known as type I, was nonexpansive, but nevertheless contributed to enhancement of the strength. Our previous work (Kamon et al. 1988) revealed that the strength degradation due to the expansion of ettringite was not found when stabilized loam soils were soaked for 24 hr (before  $q_u$  strength test), and for 96 hr (before California Bearing Ratio Test).



Figure 5. SEM analysis of loam stabilized with 12 percent NCS after 90 days, illustrating intercrossing of ettringite crystals between soil particles. (Et refers to ettringite)

Figure 6 illustrates a semiquantitative correlation between the strength gained and diffraction intensity of ettringite, with all the treated specimens. It can be concluded that strength of the stabilized soils increases with an increase of ettringite formation.

The observation just described thus brings to light another important role of ettringite in stabilizing soil, other than the effects of ettringite formation in portland cement concrete. It is believed that the contribution of ettringite to the development of strength, particularly in soil with a high moisture content, is mainly for two reasons. First, the crystals of ettringite combine with large amounts of water, thus causing a significant decrease in moisture content, which leads to an increase in the dry density of stabilized soil. Second, extracting water that exists in pore spaces by ettringite provides a reduced water ratio which aids further hardening.

Figure 7 shows that in the early stage there is a more significant reduction in moisture content in NCS-soil mixtures than in soil-cement mixtures. If some amount of hydration water was combined to form ettringite, the moisture content was then partially decreased, according to ettringite formation, resulting in a reduced water ratio of the phases. Since it was found that ettringite was produced in higher amounts in NCS-soil mixtures than in soil-cement mixtures, it was therefore concluded that a lower water-to-cementitious ratio (w/c ratio) was obtained in the former. Consequently, the remainder of the water that disappeared was assumed to be combined in the other reaction products such as CSH, resulting in further reduction of moisture in the mixtures. This effect is found to be more enhanced in the NCS-soil mixtures, compared to the soil-cement mixtures. Results from XRD as shown in Figure 8 substantiated that CSH was present at almost the same intensity in both

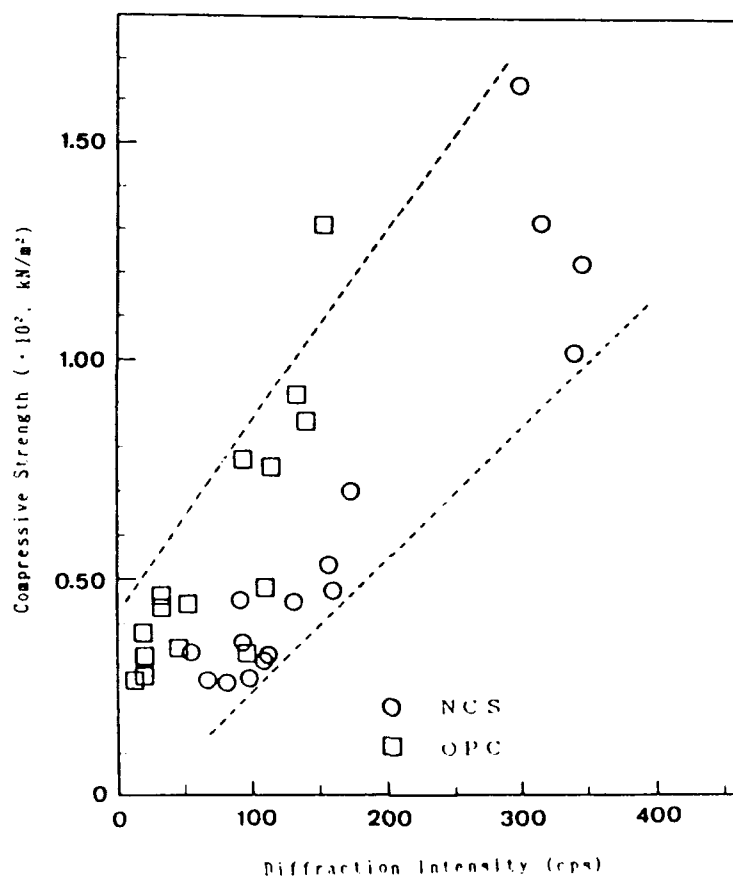


Figure 6. Semiquantitative correlation between strength and diffraction intensity of ettringite for all mixtures

mixtures, although it would have been expected that more would be produced in the soil-cement mixtures, since it contained more  $C_3S$  compounds.

#### CONCLUSIONS

Based on the experimental results, it is concluded that a new stabilizer which is produced from the incineration of various proportions of industrial wastes, combined with lime in specific chemical compositions, has self-cementing characteristics similar to OPC. It can be added to loam soil containing a high moisture content and organic matter for subgrade stabilization purposes. The newly developed stabilizer has the following advantages:

- a. Compared to conventional incineration, the developed technology described here provides a possible alternative for the treatment of industrial wastes.
- b. Converting the industrial wastes into detoxified and useful material not only has environmental benefits, but also may conserve natural resources by creating new materials for engineering construction.

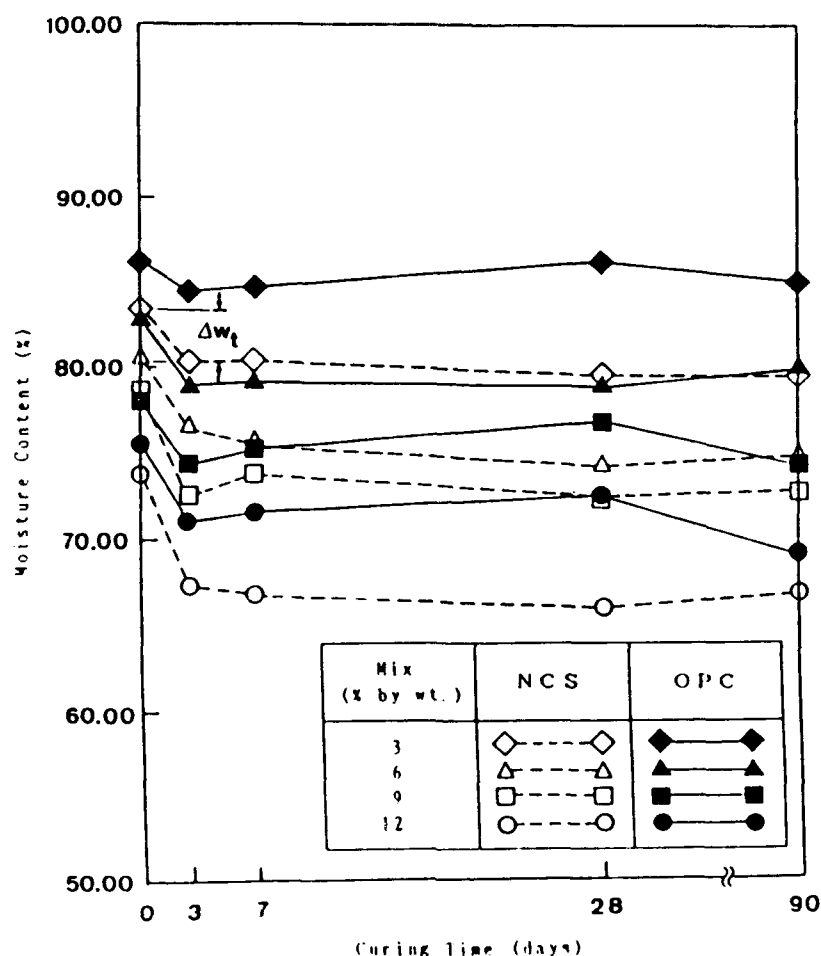


Figure 7. Observation of changes in moisture content with curing time

The results of this study bring to light some characteristics of ettringite in stabilizing loam soils. The crystals of ettringite play essential roles in strength development because of the fixation of high amounts of hydration water. This characteristic leads to an increase in dry density and a decrease of the w/c ratio in the pore.

It may not be possible to eliminate the problem concerning the chemical compositions of waste products which may change from time to time. However, the quality of this cement-like material can be controlled by strictly checking the chemical compositions, particularly those of the main oxides, using the calculated hydration modulus of 1.78 as a guideline, prior to each mix design. Future plans include studying the effect of variation of the calculated hydration modulus, particularly at values approaching 2.4, which it is believed would significantly improve the stabilized material's strength.

#### ACKNOWLEDGMENT

The authors sincerely acknowledge their debt to Professor K. Akai of the Department of Civil Engineering, Kyoto University, for his continuing

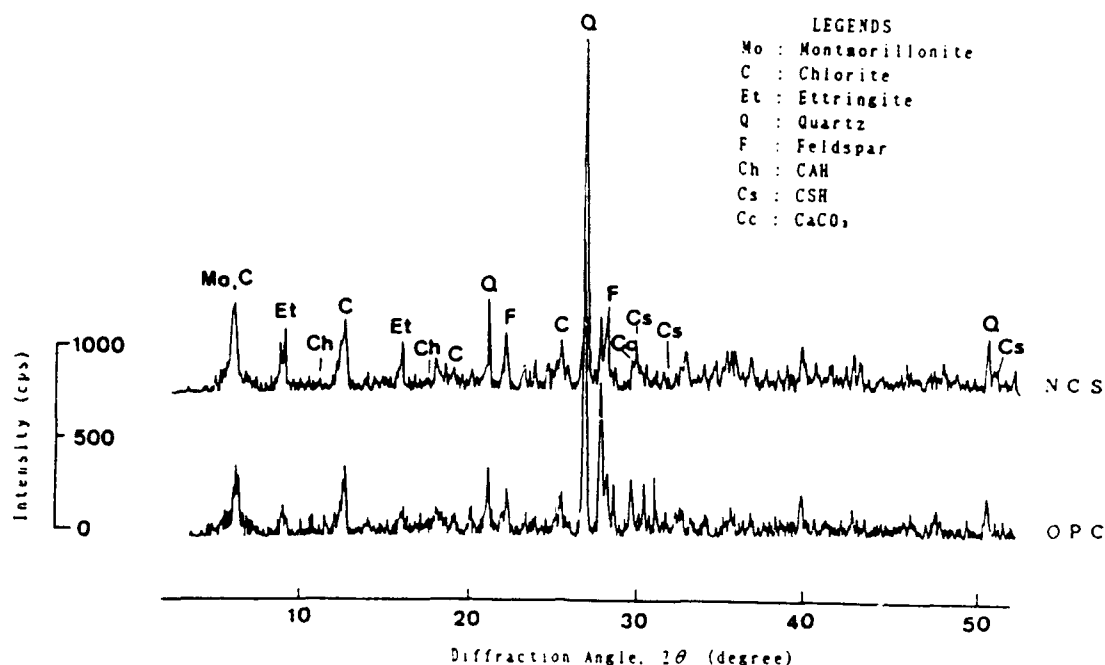


Figure 8. X-ray diffraction patterns for loam mixtures containing 12 percent NCS in comparison with 12 percent OPC after 3 days

encouragement. A special note of appreciation is expressed to Dr. A. Ohta and Mr. Y. Shida of Tokiwa Kogyo Company, Ltd., for their cooperative efforts.

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APPENDIX I. EFFLUENT STANDARD ACCORDING TO CLEAN WATER LAW  
OF JAPAN TOXICITY TEST RESULTS

<u>Contaminant</u>	<u>Maximum Allowable Concentration, in mg/l per liter of extractant</u>	<u>EA* Toxicity Test Results, in mg/l per liter of extractant</u>
Arsenic	0.5	<0.1
Cadmium	0.1	<0.1
Chromium	0.5	<0.1
Copper	3.0	<0.1
Iron	10.0	<1.0
Lead	1.0	<0.1
Manganese	10.0	<0.1
Nickel	3.0	<0.1
Zinc	5.0	<0.1

\* Environment Agency of Japan.

DEVELOPING SEDIMENT QUALITY STANDARDS:  
COMPREHENSIVE SEDIMENT MANAGEMENT IN PUGET SOUND

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AD-P006 465



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ABSTRACT

High concentrations of potentially harmful toxic chemicals have been identified in the sediments of a number of urban-industrial bays in Puget Sound. In these areas, field studies have documented an increased frequency of fish disease, sediment toxicity, altered benthic communities, and significant bioaccumulation of harmful chemicals in the edible tissue of fish and shellfish. In response to this information, and a growing public concern about the health of the estuary, the Washington State Department of Ecology has established a comprehensive strategy for sediment management in Puget Sound. As a component of this strategy, the agency is now in the process of developing a suite of sediment management standards for use in a variety of regulatory programs. General sediment quality standards are now available in draft form. Once finalized and officially adopted, the standards will be used to identify and designate sediments that have adverse effects on biological resources or pose a health risk to humans. It is anticipated that the general sediment quality standards will also be used as a basis for limiting industrial and municipal discharges, thereby preventing future sediment contamination. Separate, but related, sediment management standards are also being developed for use in establishing cleanup goals for sediment remediation and in making environmentally safe decisions concerning the disposal of contaminated dredged material. The Department of Ecology will be using the apparent effects threshold approach, supplemented by the equilibrium partitioning approach, as the technical basis for the derivation of the sediment standards. Field validation studies indicate that these methods can be used to generate chemical-specific standards which are reliable predictors of adverse environmental impacts associated with sediment contamination in Puget Sound. These methods represent tools with potential widespread application.

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## INTRODUCTION

On December 29, 1987, the Washington State legislature adopted the Puget Sound Water Quality Management Plan. Prepared by the Washington State Puget Sound Water Quality Authority (PSWQA), in cooperation with the US Environmental Protection Agency (USEPA), this plan (known as the PSWQA plan), identified existing and emerging environmental problems in Puget Sound, established environmental goals for the restoration and protection of the estuary, and detailed specific actions to be taken by Federal, state, and local governments toward achieving those goals. The PSWQA plan addressed a variety of environmental issues, including point and nonpoint source pollution, wetlands protection, environmental monitoring, and contaminated sediments. This paper summarizes the PSWQA plan's recommendations concerning sediment contamination, and describes the comprehensive regulatory framework and technical approach currently being developed in Washington State to identify and manage contaminated sediments in Puget Sound.

### A COMPREHENSIVE STRATEGY FOR SEDIMENT MANAGEMENT

The PSWQA plan established a long-term management goal for sediment quality in Puget Sound. The goal, "to reduce and ultimately eliminate adverse effects on biological resources and humans from sediment contamination throughout the Sound by reducing or eliminating discharges of toxic contaminants and by capping, treating, or removing contaminated sediments," will not easily be achieved. Sediments in many parts of Puget Sound, particularly the nearshore, urban, and industrial areas, are currently contaminated with high levels of potentially toxic substances, including heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, and other organic chemicals. The past and present sources of these contaminants are diverse, including urban runoff and a variety of industrial and municipal discharges. Field studies conducted in Puget Sound in the early and mid-1980s documented increased prevalence of sediment toxicity, altered bottom-dwelling communities, and histopathological disease in fish and shellfish living in association with contaminated sediments. Recent evidence of significant bioaccumulation of cancer-causing chemicals in fish tissue has prompted several health departments in the Puget Sound region to advise residents to limit their consumption of locally harvested seafoods.

Past efforts to prevent sediment contamination and to identify, manage, and clean up contaminated sediments in Puget Sound were hampered by the absence of adopted state or Federal sediment quality standards or criteria. Recognizing this void, the PSWQA plan identified an overall strategy for sediment management (PSWQA 1987). The strategy consists of four key elements:

- a. Classification of sediments in the Sound that cause adverse biological effects.
- b. Implementation of Sound-wide source control to prevent future sediment contamination.
- c. Provision of rules and sites for the disposal of contaminated and uncontaminated dredged material.

- d. The development of guidelines for use in sediment cleanup actions at heavily contaminated sites.

In response to this overall strategy, and the goals set forth in the PSWQA plan, the Washington State Department of Ecology (WDOE) initiated the development of a comprehensive sediment management program for Puget Sound in 1987. Integral to this program is the development of five categories of sediment management standards: (1) general sediment quality standards, (2) effluent particulate discharge limits, (3) disposal standards for unconfined dredged material, (4) disposal standards for confined dredged material, and (5) cleanup guidelines for sediment remedial action at highly contaminated sites. These standards are currently in varying stages of development.

#### General Sediment Quality Standards

In December 1989, WDOE issued the general sediment quality standards in draft form. The draft standards are now undergoing public review and comment. WDOE anticipates formal adoption of the general standards by regulation, in June 1990. Once adopted, the general sediment quality standards will serve the dual purpose of (1) reaffirming the water quality goals (i.e., maintenance and protection of human health and biological resources) already established for Puget Sound in Washington State's water quality standards, and (2) identifying specific chemical and biological criteria (i.e., acceptable levels of chemicals in sediments, bioassay toxicity limits) which must be met to ensure protection of the beneficial uses of the estuary. As required in the PSWQA plan, the general sediment quality standards will enable the identification and designation of sediments that have acute or chronic adverse effects on biological resources or pose a significant health risk to humans. It is currently anticipated that the standards will include chemical, physical, and biological tests and clearly defined pass/fail guidelines for the tests. In addition, the sediment quality standards will describe the intended use of the chemical and biological tests and clearly defined pass/fail guidelines for the tests. In addition, the sediment quality standards will describe the intended use of the chemical and biological criteria and describe variance procedures for a variety of regulatory programs. The methods that will likely be used to identify chemical concentration limits for the general sediment quality standards are discussed in a later section of this paper.

#### Effluent Particulate Discharge Limits

The WDOE is also required by the PSWQA plan to develop procedures for limiting discharges of pollutants to Puget Sound. The purpose of these procedures will be to ensure that future effluent discharges do not result in violation of the general sediment quality standards and that the potential for future sediment contamination is minimized. It is currently anticipated that final rules addressing effluent control limits and the relationship between effluent control and the general sediment standards will be issued by WDOE in June 1990. WDOE is currently considering a variety of approaches for enhanced control of pollutant discharges, including, but not limited to, reliance on best available technology, numerical limits on the toxicity of the particulate fraction of the effluent, and numeric limits on the mass or concentration of chemicals discharged. As part of the discharge management strategy, WDOE is contemplating the establishment of sediment impact zones in wastewater discharge permits. Conceptually, sediment impact zones would be similar to

dilution or mixing zones in the water column, and would be represented by a limited area near a discharge point in which limited exceedance of sediment quality criteria would be permissible.

#### Dredged Material Disposal Standards

The rules governing the management of dredged material in Puget Sound are currently in various stages of development. Procedures and guidelines for identifying disposal sites and for evaluating relatively uncontaminated sediment and disposing of the material at unconfined, open-water sites were established in 1988 as part of the PSDDA, the Puget Sound Dredged Disposal Analysis. PSDDA is a cooperative program sponsored jointly by the US Army Corps of Engineers, the USEPA, WDOE, and the Washington State Department of Natural Resources. The PSDDA sediment evaluation procedures, which combine chemical evaluation of sediment and biological toxicity testing (PSDDA 1988), are now being implemented in Puget Sound by Federal and state agencies. WDOE will formally endorse the PSDDA standards for unconfined dredged material disposal as part of the state sediment management strategy in July 1990.

Procedures for evaluating moderately to heavily contaminated dredged material, and guidelines for safe disposal of this material in confined upland or nearshore containment areas are currently being developed. As called for in the PSWQA plan, the "confined disposal standards" are to be used by WDOE and local governments in the dredged material permit process and shall address treatment and disposal options for contaminated dredged material both in water and on land. WDOE anticipates the adoption of the final confined disposal standards in July 1990.

#### Sediment Remedial Action Guidelines

Finally, the PSWQA plan directs WDOE to develop standards for deciding when heavily contaminated sediments should be capped, excavated, or otherwise treated. The sediment cleanup remedial action guidelines which will serve this purpose are currently being developed. When finalized, the guidelines will specify chemical concentration trigger levels for use in identifying sites for expedited remedial action. In establishing these guidelines, WDOE is including consideration of the roles of source control and pollution prevention, natural recovery, and maintenance dredging in sediment cleanup. It is not anticipated that all sediments which exceed the general sediment quality standards will be subject to cleanup per the state remedial action guidelines. Rather, the PSWQA plan allows that a distinction be made between low to moderate exceedance of sediment quality goals and extreme circumstances (i.e., exceedance of sediment remediation trigger levels) that warrant direct intervention. It is anticipated that only the most heavily contaminated, and thus the highest priority, sediments in Puget Sound will exceed the remedial action trigger levels and be subject to expedited cleanup. It is anticipated that WDOE will adopt final remedial action guidelines in June 1990.

#### EVALUATION OF METHODS FOR DEVELOPING SEDIMENT QUALITY STANDARDS

When the PSWQA plan first directed WDOE to develop a comprehensive program for sediment management, it was understood that innovation would be required because of the absence of formally adopted Federal sediment standards or criteria. It was also understood that the sediment assessment methods used

in standards development and source control in Washington State would likely represent application of new and controversial techniques.

Over the past decade, a variety of techniques have been developed by Federal, regional, and state agencies in the United States for evaluating the significance of chemical contamination in sediments. Many of the early efforts involved simple comparisons of chemical concentrations at contaminated sites to concentrations in sediments from relatively unpolluted reference areas. Later, more sophisticated methods were developed which not only incorporated consideration of sediment chemistry, but also attempted to establish relationships between specific concentrations of individual chemicals in sediment and associated adverse biological and human health effects. As a first step in developing sediment standards for Puget Sound, the WDOE and USEPA evaluated a variety of field-based and laboratory-based approaches to establishing numerical sediment criteria. The specific methods that were considered by WDOE and USEPA are listed below.

#### Field-Based Approaches

- Reference Area Comparison. Sediment quality values derived based on comparison of chemical concentrations at a site with concentrations at an acceptable reference area (i.e., a relatively unpolluted site with otherwise similar sediment characteristics).
- Field-Collected Sediments Bioassays. Sediment management decisions made by exposing test organisms in the lab to field-collected sediment. Comparisons are then made between the mortality or sublethal effects observed in field sediments and effects observed in experiments using sediment from a relatively unpolluted reference area.
- Screening Level Concentration. Sediment quality values determined using field samples to identify the sediment concentration above which 95 percent of the enumerated benthic infauna species are present.
- Sediment Quality Triad. Sediment quality values qualitatively derived by analyzing relationships among contaminant concentrations in sediment, the results of sediment toxicity bioassays, and the characteristics of in situ benthic communities.
- Apparent Effects Threshold. Sediment quality values quantitatively derived by using synoptically collected sediment chemistry, benthic infauna effects, and sediment bioassay data to determine the chemical concentration in sediment above which statistically significant biological effects are always observed.

#### Laboratory/Theoretically Based Approaches

- Water Quality Criteria/Interstitial Water. Concentrations of chemicals in sediment interstitial water are measured and compared directly to the USEPA chronic water quality criteria.

- Sediment-Water Equilibrium Partitioning. Sediment quality values derived by using a theoretical model to predict the partitioning of contaminants between sedimentary organic carbon and interstitial water. Predicted interstitial water concentrations are then compared directly to the USEPA chronic water quality criteria.
- Sediment-Biota Equilibrium Partitioning. Sediment quality values determined by using a model to estimate the sediment concentration of a contaminant that would be expected to result in a body burden of the contaminant in benthic organisms exceeding a regulatory limit (e.g., the US Food and Drug Administration limits for chemicals in fish and shellfish).
- Spiked Sediment Bioassays. Test organisms are exposed to sediments that have been inoculated with known amounts of chemicals. Dose/response relationships are then used to identify chemical concentrations which do not result in adverse biological impacts.

Generally, the field-based approaches evaluated by WDOE and USEPA relied on empirical observations of biological and/or chemical measurements to establish sediment quality values. Approaches such as the Triad and Apparent Effects Threshold methods identified relationships between specific concentrations of chemicals in field-collected sediments and adverse biological responses to exposed organisms. The laboratory/theoretically-based approaches evaluated by WDOE and USEPA generally relied on extrapolation of Federal water quality criteria to sediments, models of environmental interactions, or extrapolation of laboratory studies to develop sediment quality values. A more detailed description of each of the methods listed above can be found in Barrick et al. (1989) and USEPA (1989).

#### Comparison of Approaches

In evaluating the various methods for use in sediment standards development, WDOE identified 11 criteria that enabled objective assessment of the approaches with respect to three important attributes:

- a. Applicability of the approach to existing and planned sediment management programs in Puget Sound, including those identified in the PSWQA plan.
- b. Ability of the approach to generate criteria that are reliable predictors of adverse environmental effects.
- c. Feasibility of implementation of the approach in the near term (i.e., by 1990).

Specifically, each approach was evaluated based on the following 11 criteria:

- a. Data requirements and cost of sediment quality standards development.
- b. Cost of routine application as a regulatory tool.
- c. Ability to develop chemical-specific sediment quality standards.

- d. Ability to develop sediment quality values for a wide range of chemicals.
- e. Current availability of values for a wide range of chemicals of concern in Puget Sound.
- f. Ability to incorporate the influence of chemical mixtures in sediments.
- g. Ability to consider adverse effects on a range of biological indicator organisms.
- h. Extent to which the approach incorporates direct measurement of sediment-associated biological effects.
- i. Compatibility of approach to use of historical sediment chemistry data.
- j. Ease and extent of field verification in Puget Sound.
- k. Extent to which the approach provides proof of a cause/effect relationship between concentrations of specific chemicals in sediment and adverse biological effects.

Table 1 (adapted from Barrick et al. 1988) summarizes the results of WDOE's comparative analysis. The table highlights the relative advantages and limitations of each of the methods as gauged against the 11 evaluation criteria. For simplicity of presentation, each approach was assigned a subjective scoring of "-", "0", or "+" to enable a relative comparison based on each criterion. A "-" has been assigned in cases in which an approach does not meet the conditions of the criterion (e.g., relative to a cost criterion, a method is expensive to develop); a "0" was assigned in cases in which an approach somewhat meets the conditions of a criterion (e.g., an approach may be moderately expensive to develop); and a "+" is assigned in cases in which an approach substantially or fully meets the conditions of a criterion (e.g., an approach is not expensive to develop). In cases in which a criterion is not applicable to an approach, "N/A" is assigned. A more complete analysis of the advantages and limitations of each method and the scoring rationale for each criterion can be found in Barrick et al. (1988).

Of the nine methods reviewed, two were considered by WDOE to be the most promising for developing potential sediment quality standards for Puget Sound: the apparent effects threshold (AET) approach and the sediment-water equilibrium partitioning (EP) approach. Descriptions of the AET and EP approaches and a brief discussion of the technique used to field-validate sediment quality values derived from these methods are presented below.

#### Apparent Effects Threshold Approach

The AET approach estimates concentrations of a given sedimentary contaminant above which statistically significant ( $P = 0.05$ ) adverse biological effects are always expected (USEPA 1989a). The AET values for individual chemicals or groups of chemicals are derived from actual sampling data and are based on the statistical relationship between the contaminant level measured

**TABLE 1: SUMMARY EVALUATION OF AVAILABLE SEDIMENT QUALITY  
VALUE APPROACHES RELATIVE TO USE IN PUGET SOUND  
SEDIMENT MANAGEMENT PROGRAMS**

Evaluation Criteria	Reference Area	Field Collected Sediment Bioassay	Screening Level Concentration	Sediment Quality Triad	Apparent Effects Threshold	Water Quality Criteria	Equilibrium Partitioning (Sediment-Water)	Equilibrium Partitioning (Sediment-Biota)	Spiked Sediment Bioassay
Generally low data requirements and low cost of sediment quality value development	0 (+) <sup>a</sup>	0 (+)	-	- (0)	- (+)	-	+	+	-
Routine application as regulatory tool is probably not costly	0	+	0	0	0	-	0	0	0
Allows for the development of chemical-specific values	+	-	+	+	+	+	+	+	+
Allows for the development of sediment quality values for a wide range of chemicals	+	-	+	+	+	0	0	0	+
Values for a wide range of Puget Sound problem chemicals are currently available	+	NA	-	-	+	-	-	-	-
Incorporate the influence of chemical mixtures in sediments	-	+	+	+	+	-	-	-	+
Incorporates a range of biological indicator organisms	-	+	+	+	+	+	+	+	0 <sup>d</sup>
Incorporates direct measurement of sediment biological effects	-	+	+	+	+	-	-	-	+
Predictions are generally applicable to historical sediment chemistry data	+	-	+	+	+	-	0	0	+
Has been field verified to some extent in Puget Sound	NA	+	-	0	+	-	0	-	-
Provides proof of cause-effect relationships between chemicals and biological effects	-	-	-	-	-	-	-	-	+

<sup>a</sup> Parentheses indicate score based on the relative incremental cost of developing the approach for application in Puget Sound.

<sup>b</sup> Assumes equal level of development for all approaches (i.e., equal number of sediment quality values for each approach).

<sup>c</sup> The triad approach is primarily a method for intercomparing sediment chemistry and biological effects information, but can be used to subjectively estimate sediment quality values for specific chemicals.

<sup>d</sup> A range of organisms could be used in the spiked bioassay approach with a wide range of contaminants, but at present appears to be too costly and time-consuming to be practical.

<sup>e</sup> Proof under controlled laboratory conditions only

in field-collected sediments and the results of biological tests conducted on the same sediments. The approach is appropriate for use with any organic or inorganic contaminant and does not require a priori assumptions concerning the specific mechanism for interactions between contaminants and organisms (Beller et al. 1986). AET-based sediment quality values can be developed for any biological effects indicator that can be statistically evaluated relative to reference conditions. Two kinds of biological effects indicators have been used in developing Puget Sound AET: sediment toxicity bioassays and benthic community evaluations.

The laboratory bioassays that have been used to date in Washington State to develop AETs are the amphipod mortality bioassay (using *Rhepoxynius abronius*), the oyster larvae abnormality bioassay (using *Crassostera gigas*), and the Microtox bacterial bioluminescence bioassay (using *Photobacterium phosphoreum*) (Barrick et al. 1988). Generally, these bioassays involve the controlled laboratory exposure of test organisms to field-collected sediment for a fixed period of time and an assessment of acute or sublethal effects resulting from the exposure. Development of AETs based on indigenous biota has been achieved by classifying and counting organisms found in sediment collected from contaminated areas and by then comparing the abundance of these organisms to conditions in appropriate reference areas.

Figure 1 illustrates the derivation of a toxicity AET for lead. Each square on the figure represents a sediment sample that was analyzed for lead (and many other chemicals) and a hypothetical measure of adverse biological response (e.g., amphipod mortality). All available sediment samples were classified into two groups: (1) samples that did induce statistically significant adverse biological response (top bar), and (2) samples that did not induce statistically significant adverse biological response (bottom bar). Lead concentrations of samples within each group were then rank ordered by increasing concentration. The AET was established by the station in Group 2 with the highest concentration that did not exhibit statistically significant biological effects (660 mg/kg lead in this example). Above the AET, noncontradictory evidence exists that only significant biological effects were observed in this data set. If the lead AET derived from this data set were applied to an independent data set, it is expected that a high percentage of samples with lead concentrations above 660 mg/kg would be associated with toxicity to this test organism, or organisms of similar sensitivity.

The AET approach focuses on the fact that sediments can have concentrations of a given chemical as high as that chemical's AET and still have no observed biological effects. Thus, it is assumed in the AET approach that effects observed at concentrations below the AET for one chemical could have resulted from unmeasured, covarying chemicals, interactive effects of multiple chemicals, or other chemicals present at concentrations above their respective AET values. The occurrence of biologically impacted stations at concentrations below the AET of a single chemical does not imply that AETs in general are not protective against biological effects. Rather, the implication is that single chemicals may not account for all stations with biological effects. Field validation studies indicate that a high percentage of all stations with biological effects can be accounted for by developing AETs for multiple chemicals.

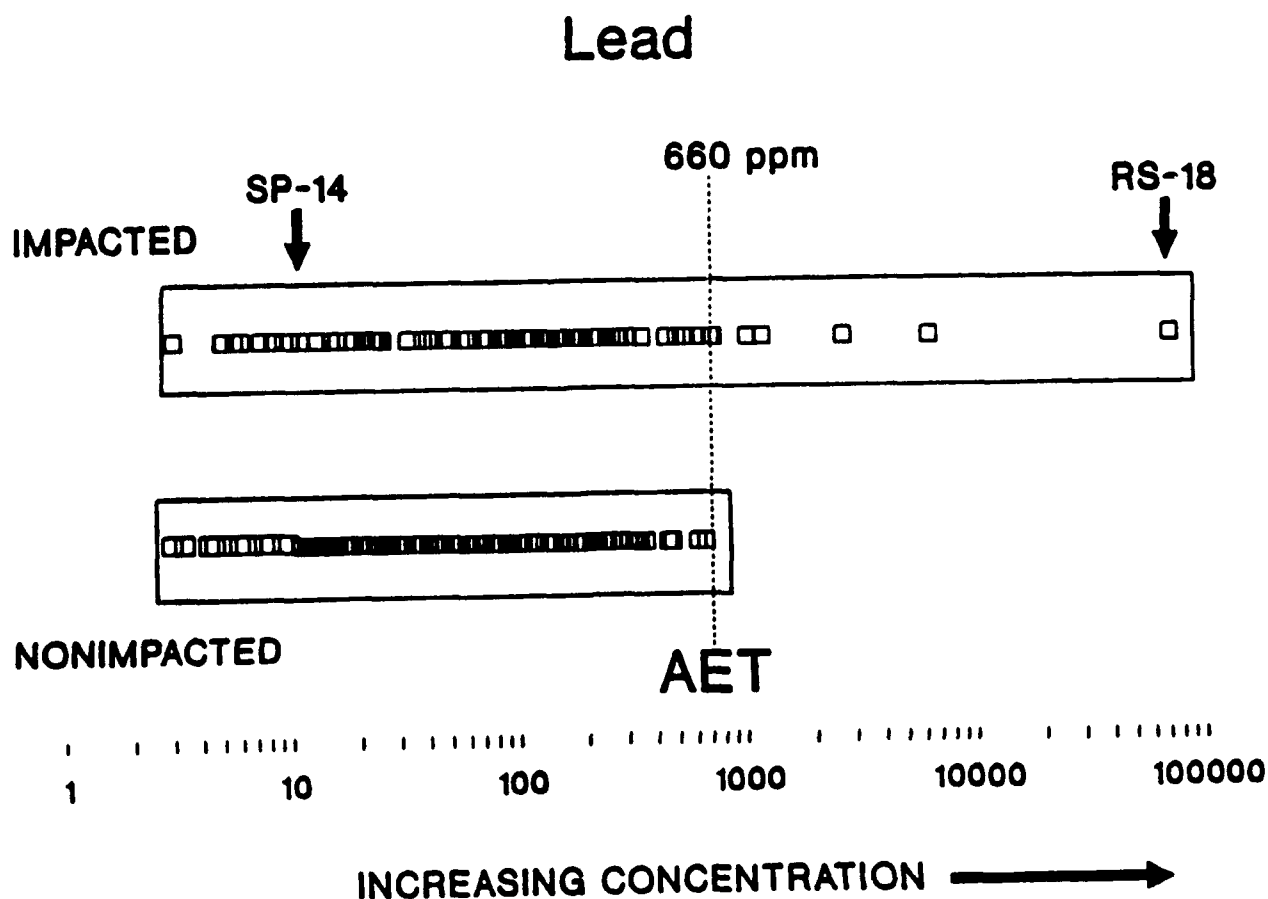


Figure 1. Derivation of AET for lead

Sediment-Water  
Equilibrium Partitioning Approach

The EP approach is based on a simple model that describes the equilibrium partitioning of a contaminant between sedimentary organic carbon and interstitial water, with little dependence on other physical or chemical factors. A sediment quality value based on the EP approach is the sediment contaminant concentration (organic carbon normalized) that would be expected to result in an uncomplexed interstitial water concentration equivalent to the corresponding USEPA chronic water quality criterion for that chemical (USEPA 1989b). If the predicted interstitial concentration for a given contaminant exceeds its respective chronic water quality criterion, the sediment would be expected to cause adverse biological effects. The approach is assumed applicable to a variety of environmental settings, including sediments with very low total organic carbon content (USEPA 1988).

The primary advantage of the EP approach is that it uses the existing EPA water quality criteria toxicological data base as a means of estimating the potential for contaminated sediment to cause adverse biological effects. Thus, use of this method does not require incurring the expense of collecting new, site-specific biological data. For nonpolar organic compounds, the EP model has a firm theoretical and empirical basis (USEPA 1988), and field

verification studies indicate that EP-based sediment criteria are reasonably predictive (Read et al. 1989). For ionic, polar organic contaminants and metals, the mechanisms controlling the partitioning of contaminants between sediment and interstitial water are not fully understood. Therefore, the ability of interested agencies to develop sediment quality standards for metals and polar organic contaminants using the EP approach is currently limited. USEPA has initiated an extensive research effort to refine partitioning models and to expand the utility of the EP approach to these groups of compounds.

#### Overview of Approach to Field Validation of Sediment Quality Values

Because none of the available approaches to developing sediment quality standards are fully capable of addressing all concerns over interactive effects among chemicals and the effects of multiple chemicals on organisms, WDOE and USEPA determined that field verification using diverse environmental samples was important to the evaluation of sediment criteria derived using the AET and EP methods.

As means of testing the predictive reliability of the AET and EP approaches when applied to field situations, WDOE and USEPA conducted a series of field validation studies (Beller et al. 1986, Barrick et al. 1988, Read et al. 1989). In designing these studies, WDOE and USEPA acknowledged that definitive confirmation of chemical-specific predictions would require additional controlled laboratory spiking studies. However, the costs associated with a large-scale laboratory program addressing many chemicals was prohibitive. Furthermore, a feasible approach was not available for confirming that the results of single chemical laboratory studies could be extrapolated, in a meaningful way, to environmental samples which contained complex mixtures of chemicals and represented a wide range of sediment conditions. As an alternative, the agencies selected an approach to field validation which relied on the use of AET and EP values to predict biological impacts associated with contaminated sediments collected from the field. Data from approximately 330 stations, representing 13 embayments in Puget Sound, were compiled into a single data base. Each station included in the data base had been subjected to extensive chemical analyses of the sediment and evaluated for sediment-associated bioassay toxicity and/or effects to indigenous benthic organisms collected from the field.

As the basis for the AET and EP evaluation, sediment chemistry results for each station were compared to two different sets of AET and EP values for a range of contaminants of concern. In the first evaluation, a comparison was made for all chemicals detected in the Puget Sound data base and available for either of the approaches (i.e., 12 chemicals for the EP approach and 60 chemicals for the AET approach). A second comparison was then made only for two chemicals, total PCBs and phenanthrene, that were widely detected in Puget Sound and common to both approaches. In both the complete and partial comparisons, exceedance of a chemical-specific AET or EP value for any one chemical at a station resulted in a prediction that the results of the biological assessment at that station would indicate adverse biological effects.

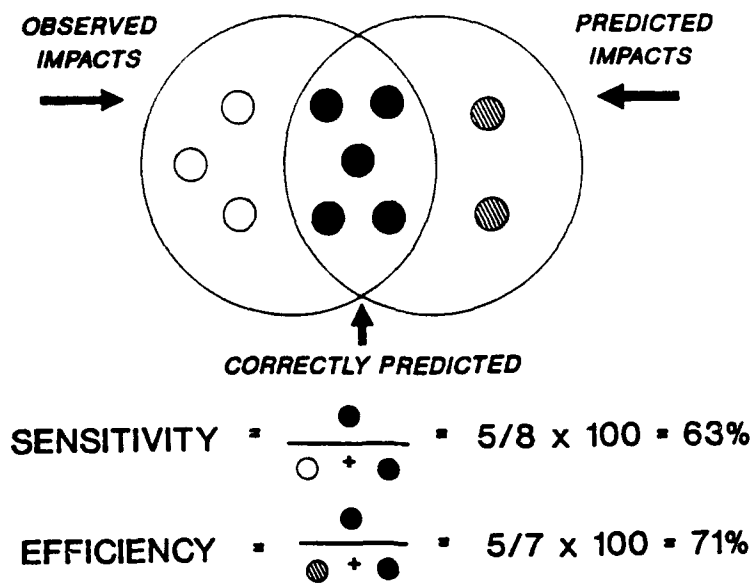
During the comparative analyses, the AET and EP predictions were evaluated according to three measures of reliability: sensitivity, efficiency, and

overall reliability. Sensitivity was defined as the proportion of all stations exhibiting adverse biological effects that were correctly predicted as impacted (i.e., all biologically impacted stations were identified as such by the AET or EP predictions). Efficiency was defined as the proportion of all stations predicted to have adverse biological effects that were correctly predicted as impacted (i.e., all biologically impacted stations were identified as such by the AET or EP predictions). Efficiency was defined as the proportion of all stations predicted to have adverse biological effects that actually were impacted (i.e., only biologically impacted stations were identified as such by AET or EP predictions). Overall reliability was defined as the proportion of all stations for which correct predictions were made for either the presence or absence of adverse biological effects. High overall reliability results from correct predictions of a large percentage of the impacted stations (i.e., high sensitivity, few false negatives) and correct predictions of a large percentage of the nonimpacted stations (i.e., high efficiency, few false positives) (Read et al. 1989). The concepts of sensitivity, efficiency, and overall reliability are illustrated in Figure 2 (Barrick et al. 1989).

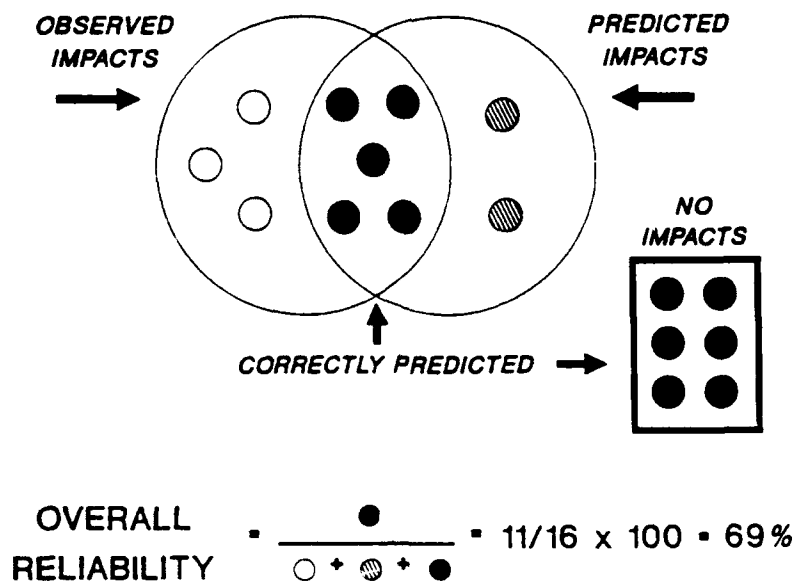
As independent measures of reliability, sensitivity and efficiency are important concepts to consider in selecting an approach to sediment management. A sediment standards approach that sets criteria for a wide range of chemicals near their analytical detection limits will probably be sensitive but inefficient. That is, it will predict a large percentage of sediments with biological effects but will also predict, as impacted, many biologically nonimpacted sediments with only slightly elevated chemical concentrations. Such an approach may be environmentally protective but also may result in overregulation that would not be cost-effective. Conversely, a sediment standards approach that sets criteria values at the upper end of the range of environmental concentrations may be efficient but insensitive. That is, a high percentage of the stations with predicted impacts may indeed be biologically impacted but the approach may fail to predict other biologically impacted stations with moderate to high chemical concentrations. Such an approach would be cost-effective and defensible in pursuing high-priority remedial actions (i.e., would not result in overregulation) but would not be environmentally protective. The overall reliability of any method for establishing sediment criteria addresses both sensitivity and efficiency and provides perspective relative to the ability of potential sediment quality criteria to balance the need for environmental protection and cost-effective environmental regulation.

#### Results of Field Validation of Sediment Quality Values

The results of the field validation comparison using all available sediment quality values indicated that the Puget Sound AET (i.e., mixed organic carbon/dry weight normalized AET for 60 organic contaminants and metals) had generally reliable predictors of adverse biological effects. When evaluated relative to the Puget Sound data base, the benthic AET values for the 60 contaminants demonstrated a 77 percent sensitivity, 100 percent efficiency, and an overall reliability of 88 percent in predicting the presence or absence of adverse biological effects in benthic infauna samples collected from 201 stations. Similarly, the sensitivity, efficiency, and overall reliability of the



a. Sensitivity and efficiency



b. Overall reliability

Figure 2. Measures of reliability

amphipod AET values were 55 percent, 100 percent, and 83 percent, respectively, in accurately predicting the presence or absence of amphipod mortality in laboratory bioassays performed on samples from 287 stations (Read et al. 1989).

In general, the sediment quality values generated using the EP approach were less reliable than the AET-based values when evaluated relative to the entire Puget Sound data base and all available AET. Taken in combination, the EP values (i.e., organic carbon normalized mean EP values for 12 nonpolar organic chemicals) demonstrated a 30 percent sensitivity, 65 percent efficiency, and 54 percent overall reliability in predicting adverse impacts to in situ benthos. Similarly, the EP values demonstrated a 28 percent sensitivity, 51 percent efficiency, and 63 percent overall reliability, in predicting amphipod bioassay mortality. The somewhat lower overall reliability of the 12 EP values in comparison with the 60 AET values is likely attributed to the lower number of detected chemicals for which EP values were available relative to AET values. Higher predictive reliability will likely be possible using the EP approach when partitioning coefficients for metals and polar organic contaminants become available for use in generating EP-based sediment quality criteria.

The results of the reliability tests performed using only phenanthrene and total PCB values for the AET and EP approaches indicate that the EP-based values are slightly more predictive than the AET values for these two contaminants. The demonstrated sensitivity, efficiency, and overall reliability of the EP values in predicting adverse effects to benthos at 190 stations were 29, 65, and 54 percent, respectively, compared with a sensitivity, efficiency, and overall reliability of 14, 100, and 52 percent, respectively, for the benthic AET values. Similarly, the sensitivity, efficiency, and overall reliability of the EP-based values in predicting amphipod mortality in laboratory bioassays were 27, 51, and 63 percent, respectively, compared with a sensitivity, efficiency and overall reliability of 3, 100, and 64 percent, respectively, for amphipod AET. The reduced sensitivity of AET-based sediment quality values for total PCBs and phenanthrene, relative to the sensitivity demonstrated when AET for all available chemicals were used, may reflect the fact that there are a number of areas in Puget Sound for which other nonionic organic contaminants, metals, or alkylated phenols are in high concentrations in sediments and likely contributing to site-specific toxicity.

The results of the reliability analysis suggest that elements of both the AET and EP approaches are useful in making environmental decisions. For this reason, WDOE is proposing that the Puget Sound sediment quality standards incorporate the best of both methods (i.e., that the standards for PCBs and phenanthrene be EP-based and the standards for all other contaminants be AET-based). However, the results of the reliability analyses also suggest that available chemical-specific sediment criteria alone may serve as incomplete surrogate indicators of biological effects associated with unmeasured chemicals or the interactive effects of multiple chemicals. For this reason, WDOE acknowledges that a combination of biological and chemical testing will be necessary, in the near term, for effective management of contaminated sediments. In addition to EP- and AET-based sediment standards, WDOE will be requiring confirmatory, site-specific biological testing as part of the general sediment quality standards for Puget Sound.

## CONCLUSIONS

Chemical contamination of marine and estuarine sediments in developed coastal areas is a significant problem not only in Puget Sound but also throughout the United States and internationally. The regulatory framework adopted by EPA, PSWQA, and WDOE for sediment standards development and implementation in Puget Sound will likely be the first such comprehensive program in the United States and it may well serve as an appropriate model for sediment management elsewhere. The AET and EP approaches, used as methods for establishing sediment quality standards, also have potential widespread application. The AET- and EP-based sediment quality values appear to be reasonably predictive in Puget Sound and can be generated independently for other locations. Supplemented by limited site-specific biological testing, AET- and EP-based sediment quality values provide a defensible basis for regulatory decisions concerning the identification, management, and cleanup of contaminated sediments.

For additional information on the comprehensive sediment management program being developed by WDOE, please contact Mr. Keith Phillips, Washington Department of Ecology, Sediment Management Unit, PV-11, Olympia, Washington 98504. For additional information on the AET approach, please contact Ms. Catherine Krueger, US Environmental Protection Agency, Hazardous Waste Division, HW-113, 1200 Sixth Avenue, Seattle, Washington 98101. For additional information on the EP method, please contact Mr. Christopher Zarba, Environmental Protection Agency, Office of Water Regulations and Standards, WH-585, 401 M Street S.W., Washington DC 20460.

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# SOLIDIFICATION TECHNIQUE FOR DREDGED BOTTOM SEDIMENTS

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## ABSTRACT

Bottom sediments, which cause pollution in the sea, river, and lake, have high fluidity and contain not only many organic matters with bad odor in general, but also toxic heavy metals in some circumstances.

Now in Japan, since many regulations and restrictions have been published for disposal of such sediments in the area of concentrated population and high utilization of land, it is highly necessary to stabilize the dredged sediments speedily and to provide the disposal area.

This paper presents the solidification technique for dredged bottom sediments which was developed and practiced popularly in Japan for the above purposes.

## INTRODUCTION

"Bottom sediments" are so-called "HEDORO" and defined as particles, which were in general produced through natural agencies or human activities, and then accumulated at the bottom of the lake, river, and sea. It is noted that "waste sludge" is produced through wastewater disposal at the facilities for water supply and sewerage and various factories. In this paper, "bottom sediments" include both bottom sediments and waste sludge. The solidification system is reported as one of the bottom sediments treatment systems which have been applied to dredging for purification of the environment and maintaining the water capacity.

## PROPERTIES OF BOTTOM SEDIMENTS

Bottom sediments generally have the following properties:

- a. High water content and high percentage of silt and clay particles.
- b. Often include organic matters.
- c. Include toxic substances in some cases.



- d. Have bad odor in some cases.

"Solidification technique" has been applied to one of the treatment systems in order to make the handling of bottom sediments much easier.

#### PURPOSE OF SOLIDIFICATION

First, in order to remove water from the bottom sediments to be handled, a lot of energy and a long consolidation time are required. Second, in order to minimize the leaching of toxic substances and the occurrence of the bad odor, chemical treatment shall be required.

The above conditions can be solved by the application of the solidification technique for bottom sediments. Objectives of this technique are as follows:

- a. To prevent "splash out" during the transportation of dredged sediments to the disposal area.
- b. To enable direct placement of dredged sediments on the disposal area.
- c. To allow trafficability for the construction machines on the disposal area.
- d. To utilize the dredged sediments as banking or filling materials.
- e. To lock and minimize the leaching of toxic substances.
- f. To reduce the bad odor.
- g. To stabilize the foundation of structures constructed on the disposal area.

#### CHARACTERISTICS OF SOLIDIFIED SEDIMENTS AND THEIR REQUIRED STRENGTH

The required strength and other characteristics of solidified sediments to accomplish each purpose are shown below:

##### Handling and Transportation of Sediments

Unconfined compressive strength ( $q_u$ ) for transportation by truck with 30 km/hr in average speed, 20 percent of unpaved roads out of total route, and 3-hr transportation shall be classified as follow:

- a.  $q_u \geq 0.3 \text{ kgf/cm}^2$  : easy for transportation.
- b.  $0.05 \leq q_u < 0.3 \text{ kgf/cm}^2$  : occasionally difficult (depending on the sediment properties and transportation condition).
- c.  $q_u \leq 0.05 \text{ kgf/cm}^2$  : very difficult for transportation.

A very small value of  $q_u$  (less than  $0.05 \text{ kgf/cm}^2$ ) can be estimated by the fall-cone test ( $F_c$ ). In a practical case,  $q_u$  is usually specified as the

value between  $0.5 \text{ kgf/cm}^2$  and  $1.0 \text{ kgf/cm}^2$  because of the variety of the properties considered.

### Surface Laying on the Disposal Area

Bottom sediments soon after dredging are very soft with the  $q_u$  value ranging from  $0.04 \text{ kgf/cm}^2$  through  $0.06 \text{ kgf/cm}^2$ . Even though such sediments will gradually consolidate, using the bulldozer takes too long for surface laying of sediments on the disposal area. Once surface laying is tried on the disposal area soon after dredging, sediments will easily liquify and flow out. In this case, forming a solid surface layer by solidification is so effective that surface laying work can be well executed, as shown in Figure 1. The design flow diagram for the surface solidification method is presented in Figure 2. This involves the following activities:

- a. Check the stability by the circular sliding method.
- b. Study the stress condition in the layer.
  - (1) Ultimate design method for the case of more than  $1 \text{ tf/m}^2$  in shear strength.
  - (2) Coefficient of the subgrade reaction method for the case of less than  $1 \text{ tf/m}^2$  in shear strength.
- c. Check the bearing capacity of unsolidified subgrade for the subgrade reaction due to the load.

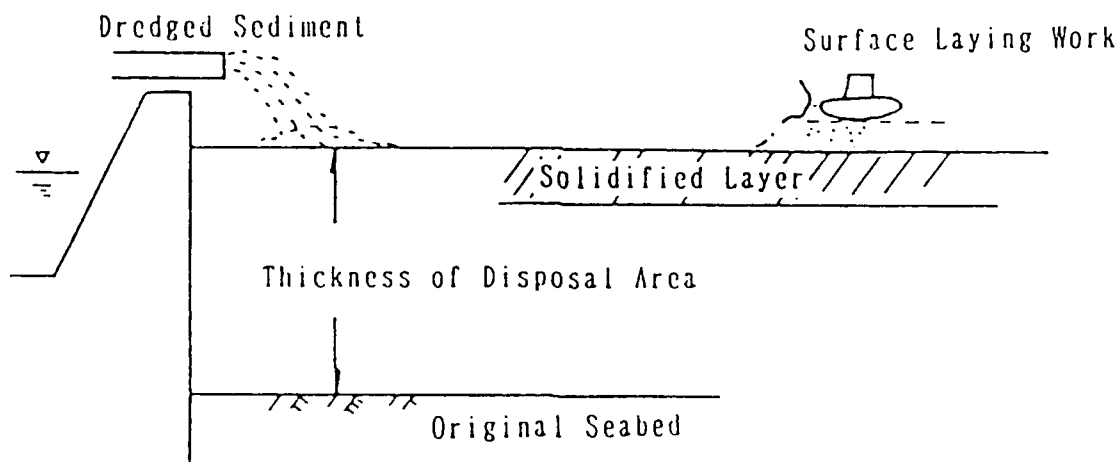


Figure 1. Solidification for surface laying work

### Trafficability on Disposal Area

The required solidified strength for trafficability of the construction equipment working in the disposal area depends on the dimensions of the machines and is generally  $q_u$  equals  $0.5 \sim 1.0 \text{ kgf/cm}^2$ . The relations between the kinds of construction equipment and the required cone index ( $q_c$ ) are shown in Table 1. Other relations between cone index ( $q_c$ ) and unconfined compressive strength ( $q_u$ ) are plotted in Figure 3.

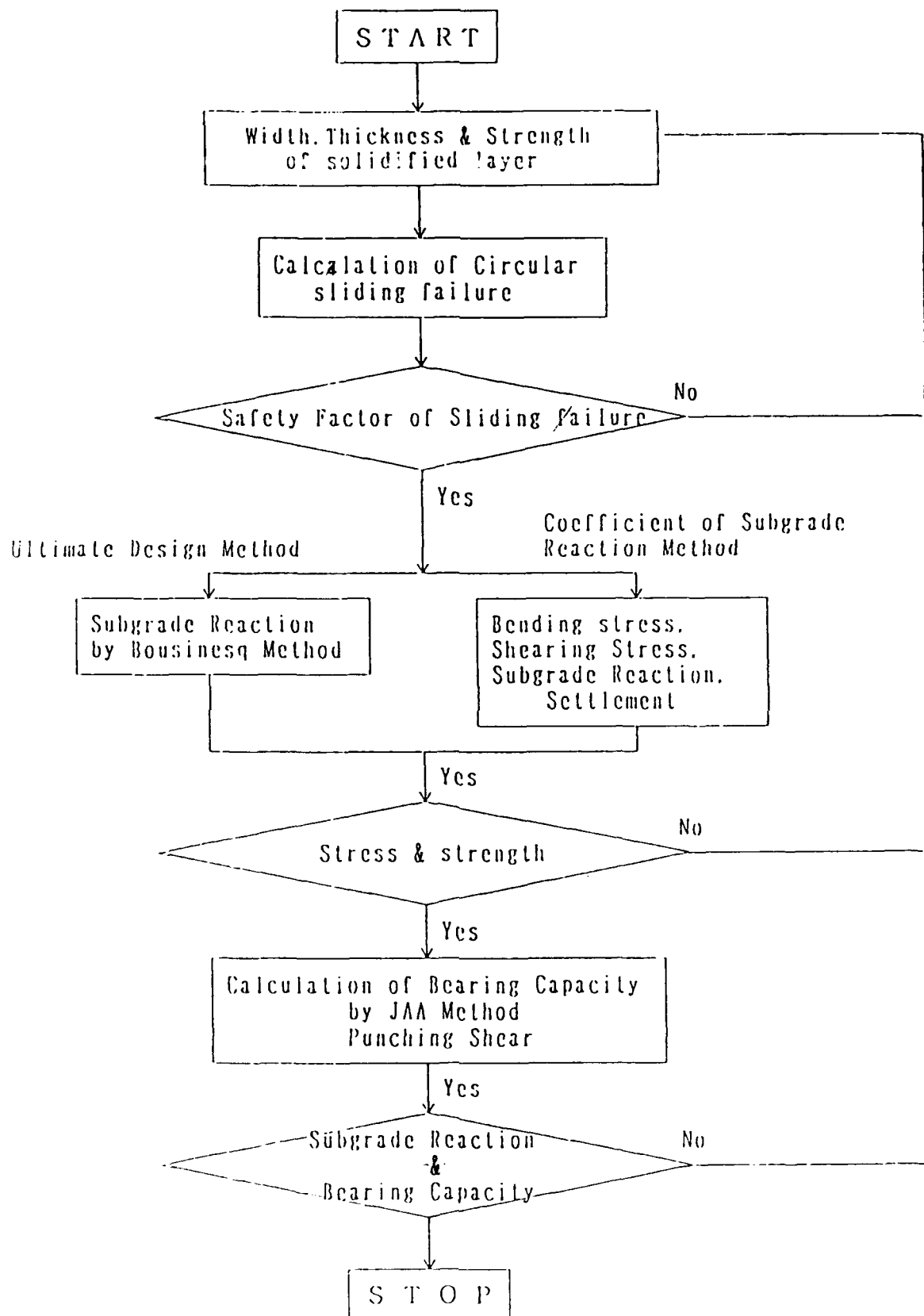


Figure 2. Flow diagram for the surface solidation method

TABLE 1. CONSTRUCTION MACHINE AND THE REQUIRED CONE INDEX

Construction Machine	Cone Index, $q_c$ ( $\text{kgf}/\text{cm}^2$ )
Special swamp bulldozer	$\geq 2$
Swamp bulldozer	$\geq 3$
Bulldozer (medium class)	$\geq 5$
Bulldozer heavy class)	$\geq 7$
Scrape-dozzer	$\geq 6$
Pulling-type scraper	$\geq 7$ (swamp type $\geq 4$ )
Motor scraper	$\geq 10$
Dumptruck	$\geq 12$

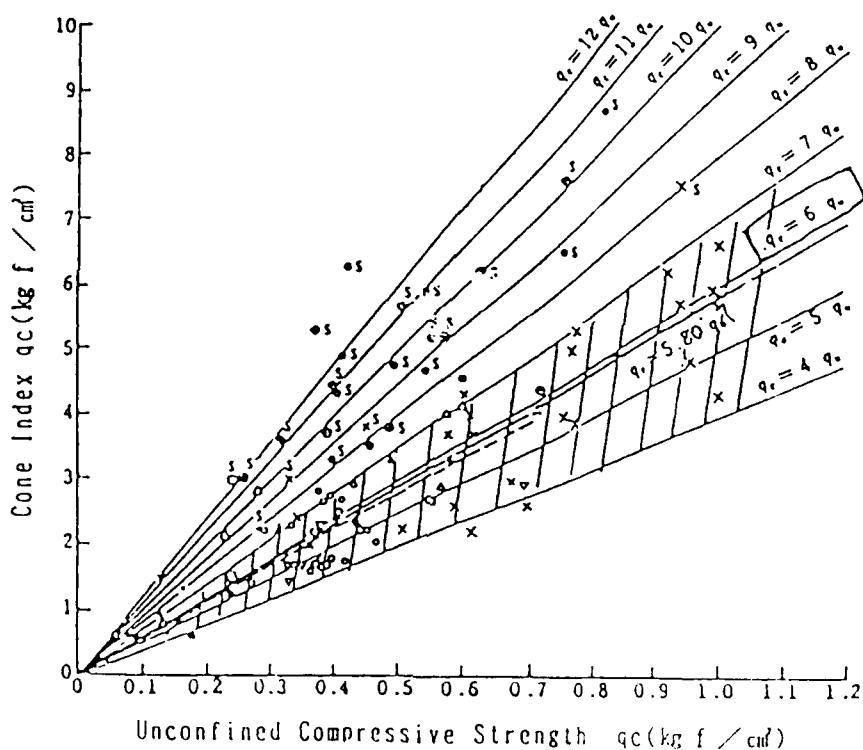


Figure 3. Cone index and unconfined compressive strength

Since the contact pressure of the construction machine is often used, the relation between contact pressure ( $P$ ) and required cone index ( $q_c$ ) is introduced as follows.

The bearing capacity of subgrade with  $\phi$  (internal friction angle) = 0 can be expressed below by Terzaghi's Bearing Capacity Formula:

$$q_d = cN_c$$

where

$q_d$  = ultimate bearing capacity of subgrade (kgf/cm<sup>2</sup>)

$c$  = cohesive strength (kgf/cm<sup>2</sup>)

$N_c$  = coefficient of bearing capacity ( $N_c = 5.3$ )

Supposing that  $q_u = 1/6 \cdot q_c$ , the relation between  $q_d$  and  $q_c$  is written as

$$\begin{aligned} q_d &= cN_c \\ &= 1/12 \cdot q_c \cdot 5.3 \\ &= 0.44 q_c \end{aligned}$$

Using contact pressure ( $P$ ) and safety factor ( $F_s$ ) for ultimate bearing capacity ( $q_d$ ), the relation between  $P$  and the required cone index ( $q_c$ ) is expressed as

$$\begin{aligned} q_c &= q_d/0.44 \\ &= F_s \cdot P/0.44 \end{aligned}$$

An example case of  $P = 0.7$  kgf/cm<sup>2</sup> and  $F_s = 3$  is shown below.

$$\begin{aligned} q_c &= 3 \times 0.7/0.44 \\ &= 4.8 \text{ kgf/cm}^2 \end{aligned}$$

#### Utilization as Banking or Filling Materials

Modulus of deformation is one of the characteristics which indicate the applicability to the construction materials. The strength of solidified soil gradually varies from plastic behavior in the early stage to rigid behavior. Stress-strain curves of three typical soils are shown in Figure 4. Soft clayey soil (curve a) has a high plasticity, and is strained considerably even under little stress. Sandy soil (b) has less strain than soft clayey soil, and solidified soil (c) has a peak stress under a little stress.

The tangent modulus of elasticity of each soil in Figure 4 may correspond to the modulus of deformation, which can be calculated by dividing half of the peak stress by relevant strain. The modulus of deformation of solidified sediments can be one of the indices for applicability to banking or filling materials. Table 2 shows the moduli of deformation of various kinds of construction materials.

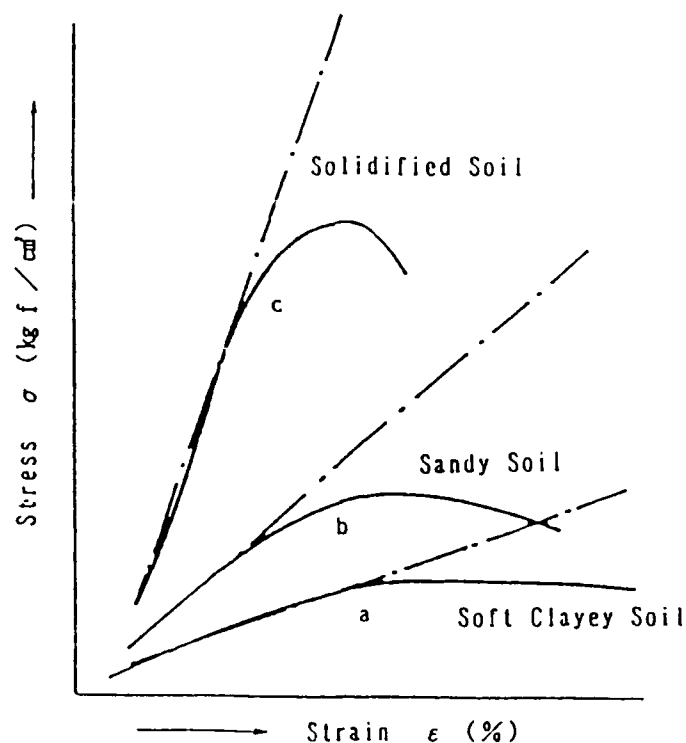
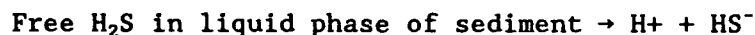


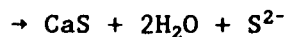
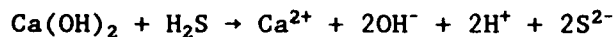
Figure 4. Stress-strain curves of soil

#### Removing Bad Odor

Each bottom sediment has its own peculiar smell which originates in the chemical production of hydrogen sulfate gas, etc., as a result of the activity of bacteria in bottom sediments. During the process of solidification by cement-type chemicals, the hydrogen-ion concentration (pH) of the bottom sediment increases to about 12. Under such a strong alkalic condition, sulfate gas, which mainly causes the bad smell, is not produced at all because of the production of calcium sulfate, as shown below.



↓ Adding  $\text{Ca}(\text{OH})_2$  which is contained in cement-type chemicals



The equilibrium of pH and sulfate ( $\text{H}_2\text{S}$ ) during the above chemical reaction is shown in Figure 5.

There is a test report of odor removal for bottom sediment at Tangonoura in Japan where sulfate ( $\text{H}_2\text{S}$ ) gas from bottom sediment caused serious pollution. In this test, 100 g of  $\text{CaO}$  was added to 10 kg of sediment and mixed for 5 min with 50-rpm churning. After 15 min, the smell of sulfate gas was completely removed, and the dark brown color of the original sediment had disappeared.

TABLE 2. MODULI OF DEFORMATION OF CONSTRUCTION MATERIALS

<u>Construction Material</u>	<u>Modulus of Deformation</u>
Soil	~ 100
Sand	100~500
Mixture of gravel, sand, and clay	500~2,000
Crushed stone	500~2,000
Soil cement	10,000
Pit sand	500
Crusher-run	1,000
Graded crushed stone	1,000
Cement-stabilized soil	15,000
Lean concrete	40,000
Bituminous macadam	2,500
Slag	1,000
Graded crushed stone	3,000
Crusher-run	1,100
Sand	350
Soft clay	5~40
Normal clay	40~80
Loose sand layer	80~150
Stiff sand layer	100~200
Compacted sand layer	500~800
Compacted gravel layer	1,000~2,000

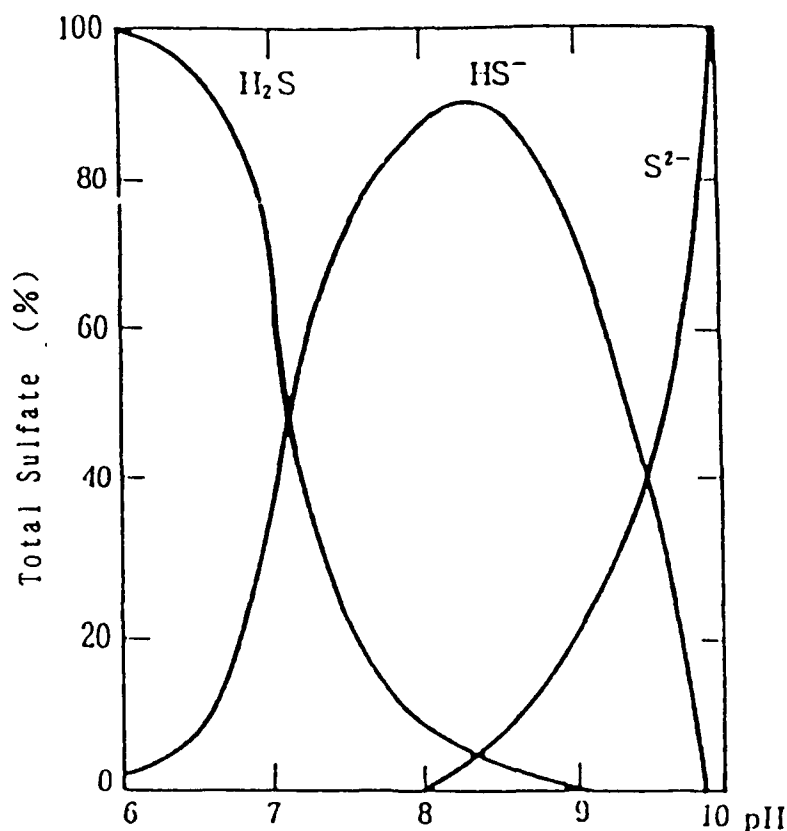


Figure 5. Equilibrium of pH and sulfate ( $\text{H}_2\text{S}$ )

On the other hand, once bottom sediments become alkaline, ammonium salts in the sediment can decompose and the resulting ammonia gas smell is offensive. Since ammonia is soluble and its solution shows weak alkalinity, neutralization by misting a weak acid (e.g.,  $\text{Al}_2(\text{SO}_4)_3$  solution) over the alkali sediment is effective in removing this odor for a certain period.

According to current Japanese regulations, eight kinds of substances are restricted, as shown in Table 3.

#### Reduction of Teaching of Toxic Substances

In solidification of bottom sediments using cement-type or lime-type chemicals, the calcium ion in the chemicals has a chemical-fixing effect on toxic substances in the sediments as well as a pozzolanic effect.

As the density of hydration ions ( $\text{OH}^-$ ) in the solution becomes high, and the liquid phase is alkalized, the metal ion ( $\text{M}^+$ ) in the solution is changed to hydrated metal with sedimentation through the following reaction:



TABLE 3. REGULATIONS FOR SUBSTANCES OF BAD ODOR

Item or Substance of Bad Odor	Chemical	Description	Upper Limit (ppm)	
			Special District	General District
Ammonia	NH <sub>3</sub>	Stimulation	5	1
Methyl melkaputhan	CH <sub>3</sub> SH	Putrefied Onion	0.01	0.002
Hydrate sulfate	H <sub>2</sub> S	Putrefied egg	0.2	0.02
Methyl sulfate	(CH <sub>3</sub> ) <sub>2</sub> S	Putrefied onion	0.2	0.01
Tri-methyl ami	(CH <sub>3</sub> ) <sub>2</sub> N	Putrefied fish	0.07	0.005
Methy di-sulfate	(CH <sub>3</sub> ) <sub>4</sub> S <sub>2</sub>	Putrefied onion, stimulation	0.1	0.009
Acetaldehyde	CH <sub>3</sub> CHO	Stimulation, boiling point 21° C	0.5	0.05
Styrene	O-CH = CH <sub>2</sub>	Stimulation	2	0.4

The hydrated metal produced through the above process has a rather low solubility, so that the density of toxic metal ions in the liquid phase decreases considerably.

The reduction of the leaching of toxic substances is achieved through the above two mechanisms, i.e., the chemical fixing effect by Ca<sup>2+</sup> and the hydration and sedimentation effect by OH<sup>-</sup>.

Figure 6 evaluates the reduction ratio of leaching of heavy metals by lime treatment, which was carried out by Bechtel Company. According to this figure, most of heavy metal ions are removed and become harmless by the production of calcium salts and hydroxide. Only Cr<sup>6+</sup> ion shows a low value of the reduction ratio.

In the case of utilization of bottom sediments in residential and public areas, standard or limit values for soil pollution, as published by the Japanese and local governments, may be applied (see Table 4).

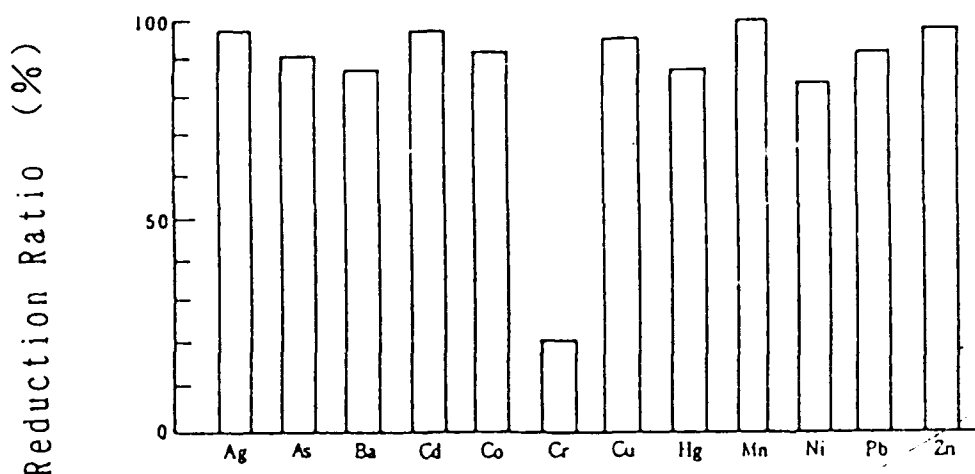


Figure 6. Reduction ratio of leaching of heavy metals by lime treatment

#### METHODS FOR SOLIDIFICATION OF BOTTOM SEDIMENTS

Methods for solidification of bottom sediments are basically classified into two types, described below.

##### In Situ Solidification Type

In situ solidification is applied at the following areas (as shown in Figure 7):

- a. Disposal area for dredged bottom sediment.
- b. Lake, sea, and river where bottom sediments deposit.
- c. Very soft ground necessary for shallow ground improvement.

##### Process Treatment Type

Process treatment solidification is applied to the following areas (as shown in Figure 8):

- a. Bottom sediment on the way to disposal area after dredging.
- b. Mud slurry produced at the site of shield works or in situ piling works.

Solidifying plants or facilities are popularly used for the process treatment type. Solidification methods are summarized in Table 5.

#### CONCLUSION

Properties of bottom sediments vary because of the different factors of origin and development processes. Treatment of bottom sediment in the construction stage is closely related not only to the design codes and standards

TABLE 4. STANDARD OR LIMIT VALUES FOR SOIL POLLUTION

Item	Content (mg/kg)			Leaching (mg/L)					
	Japanese Government	Yokohama	Tokyo	Anagasaki	Japanese Government	Yokohama	Tokyo	Anagasaki	Kyoto
Cd & its compound	9	5	5	--	--	--	0.03	0.3	0
Cyanide	--	3	5	--	1.0	--	0.1	1.0	0
Pb & its compound	600	300	300	--	--	--	0.3	3	0
Cr <sup>6+</sup> & its compound	--	--	1.0	--	0.5	--	--	1.5	--
As & its compound	50	50	50	--	--	--	0.15	1.5	0
Hg & its compound	3	3	2	--	0.005	--	00	0.05	0
PCB	--	10	10	--	0.003	--	0.001	0.003	--
Organic Hg & its compound	--	0	--	--	--	--	--	ND	--
Organic phosphorus	--	0	--	--	--	--	--	1	--
Ni & its compound	--	0	--	--	--	--	2	--	0
Cu & its compound	--	0	--	--	--	--	2	--	0
Zn & its compound	--	--	700	--	--	--	5	--	0
T-Cr & its compound	--	--	--	--	--	--	--	--	0
Phenol	--	--	--	--	--	--	--	--	0
Fluorine	--	--	--	--	--	--	--	--	0
Mn & its compound	--	--	--	--	--	--	--	--	0

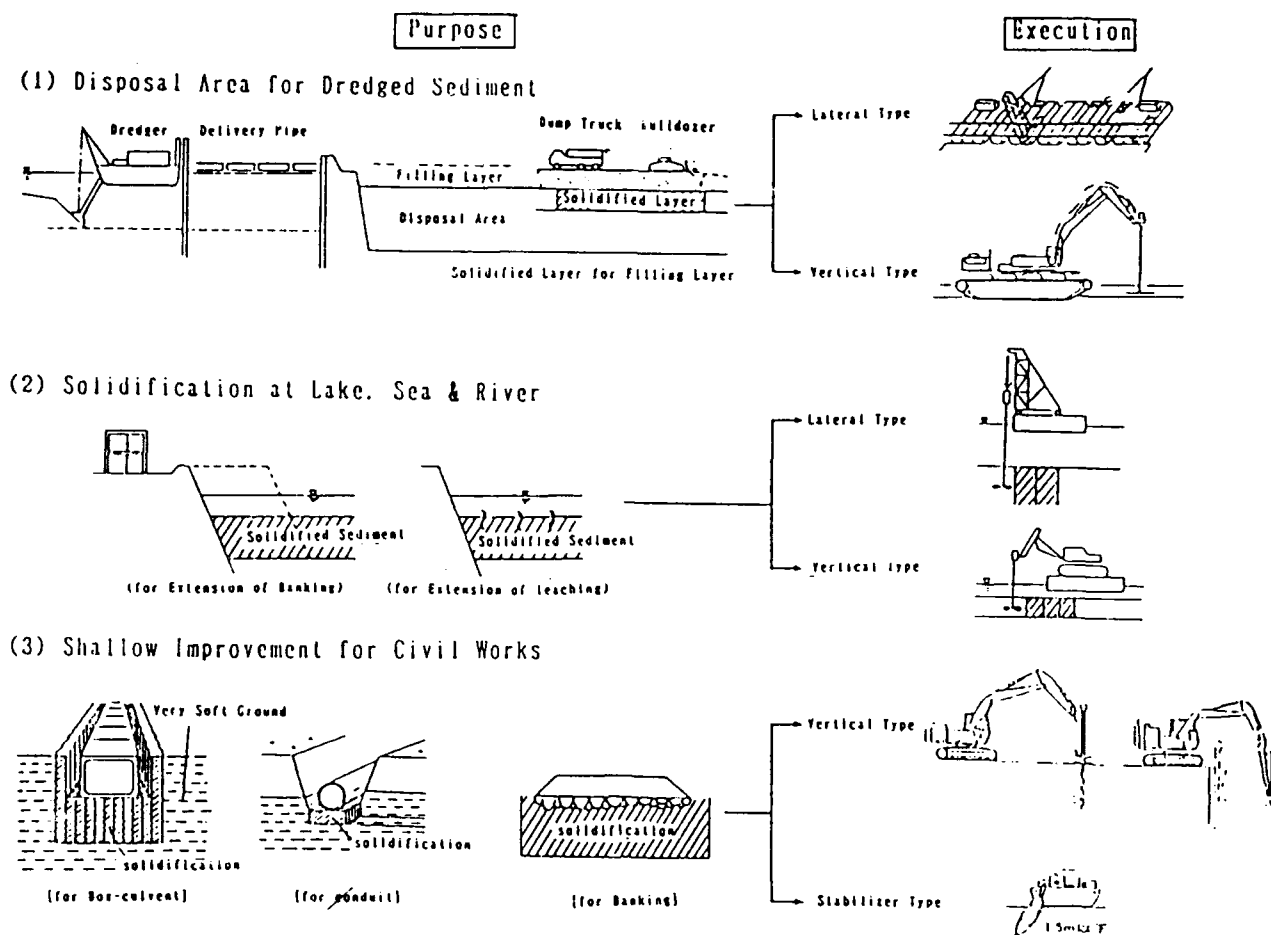


Figure 7. In situ solidification type

for civil works but also to the environmental regulations for containing the organic matters and toxic substances.

From the above point of view, the solidification technique for treatment of bottom sediments in Japan has been reported in this paper. In summarizing this paper, features of the solidification technique are shown in Figure 9.

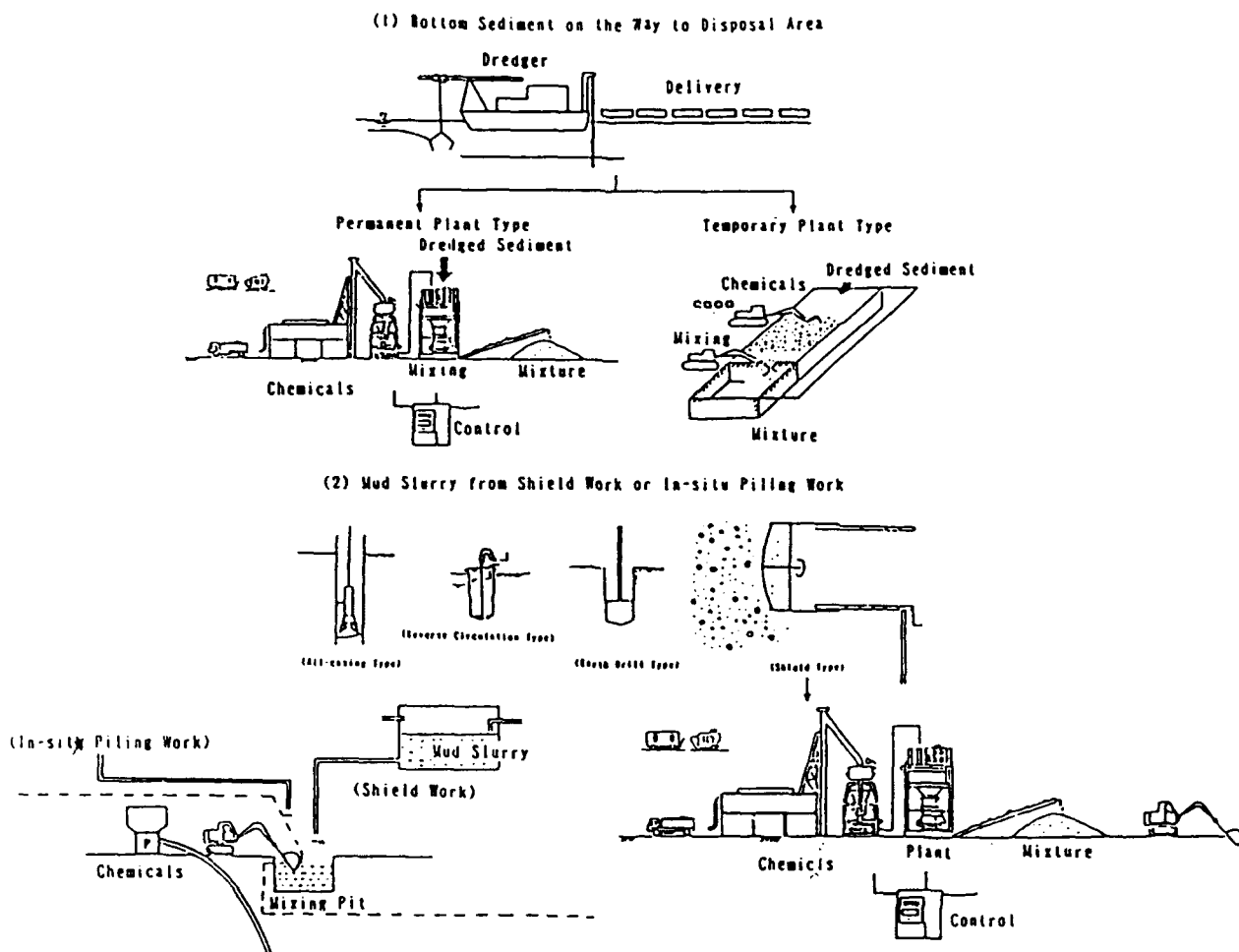


Figure 8. Process treatment type

#### SOLIDIFICATION TECHNIQUE

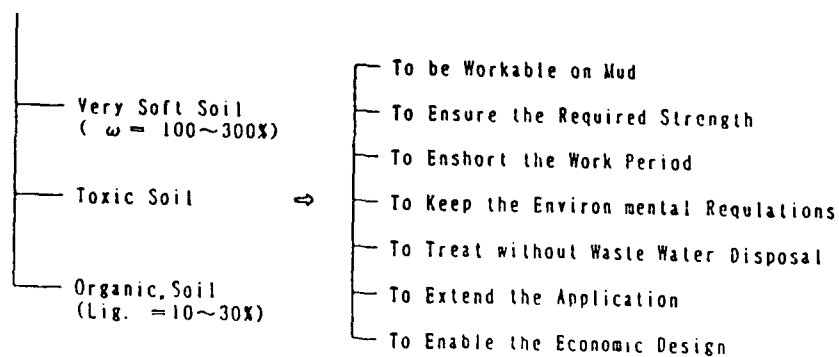



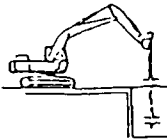



Figure 9. Features of solidification technique

TABLE 5. SUMMARY OF SOLIDIFICATION METHOD

	In-situ Solidification			Solidification by Temporary Plant	Solidification by Permanent Plant
	Lateral Type	Stabilizer Type	Vertical Type		
Use	河川改修(河工)	河川改修(河工)	河川改修(河工)	土留工	土留工
Capacity	Depth	10-20m 9.0m	less than 1.5m	less than 3.0m	1.0 ~ 2.0m
	Mixing Capacity	50-60m <sup>3</sup> /h	40-50m <sup>3</sup> /h	20-30m <sup>3</sup> /h	20-30m <sup>3</sup> /h
	Chemicals Supply	Cement Slurry	Powder or Slurry	Cement Slurry	Cement Slurry or Powder
	Workability	Workable on Mud	Workable on Mud	Workable on Mud	by Back Hoe
	Operation	Slurry Plant	Powder Feeder	Slurry Plant	Powder Feeder
Applicability	for Big-scale work	for Road Work	for Small-scale work		
Remarks					

DEVELOPMENT OF A VACUUM CONSOLIDATION METHOD  
EMPLOYING HORIZONTAL DRAINS

AD-P006 467



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ABSTRACT

A vacuum consolidation method employing horizontal drains has been developed as a way to improve very soft ground. In this method, plastic board drains are laid in extremely soft ground with roughly 1.0-m-square arrangement, and a vacuum is applied to the clayey soil from one end of the drain to consolidate and improve the soil.

From this development project, the following conclusions were reached:

- a. According to laboratory experiments conducted on vacuum consolidation, a high level of improvement equivalent to loading consolidation has been obtained when a vacuum is applied to clayey soil.
- b. From the onsite experiments, it was found to be relatively easy to lay horizontal drains in the ground.
- c. It was verified that soil in landfills produced by the disposal of dredged clayey soil and in disposal sites containing slurry can be significantly improved by this method.

INTRODUCTION

When land is reclaimed by disposing clayey soil dredged from the sea bottom when deepening sea lanes or harbor facilities, or in waste disposal sites where slurry discharged from chemical plants or other facilities is stored, ground is created which is so soft it is difficult for a person to walk on. The authors and their colleagues are engaged in the development of a vacuum consolidation method employing horizontal drains as one way of consolidating such very soft soil in a short period (References 1-5). In this method, plastic board drains, each having a square shape with sides approximately 1.0 m long, are laid horizontally in very soft soil, and vacuum is applied to the clayey soil through one end of these drains to bring about

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consolidation and improvement of the soil. The reasons why the combination of plastic board drain and vacuum consolidation was selected as the land improvement method were: (a) loading consolidation is difficult when the soil is extremely soft, and vacuum consolidation is obviously ideally suited to the situation; and (b) installation of drains was essential to reduce the consolidation time, and plastic board drains maintain their performance even in extremely soft soil.

This method has the following characteristic advantages:

- a. Extremely soft land can be settled substantially within a short period. Thus, it is possible to dispose of 1.5 times as much clayey soil on the same disposal site as compared to conventional methods.
- b. As the very soft soil is improved by applying a vacuum, the strength of the clayey soil is expected to increase even after the improvement operation. Thus, it is easier to spread sand over the surface of the land than with conventional methods.

The idea of improving very soft soil using horizontal drains has been introduced before. However, as there was no practical way to lay drains in the soil horizontally, this idea did not materialize. With the drain laying method introduced in this paper, drains can be laid in the soil very easily.

Basic laboratory experiments on vacuum consolidation are described first, and then the performance in actual soil improvement tests conducted onsite with laid drains is reported. The onsite experiments were conducted on a landfill made by a pump-type dredging vessel, which disposed clayey soil from the sea bottom, and in a disposal site for slurry.

#### BASIC LABORATORY EXPERIMENTS ON VACUUM CONSOLIDATION

One-dimensional consolidation experiments were carried out to identify the effect of vacuum consolidation on clayey soil. These experiments were conducted in order to compare the performance of this method with loading consolidation, and also to identify the effect of vacuum consolidation on the improvement of clayey soil.

##### Experimental Method

The experimental setup is illustrated in Figure 1. The vacuum used for consolidation was controlled by adjusting the pressure reading to specified values on a mercury manometer. Loading consolidation was performed by air pressure loading, and the experiments were conducted with 0.4 to 0.5-kgf/cm<sup>2</sup> back pressure.

Samples used were clay taken from Tokyo Harbor with water content controlled at  $W_0$  equals 110 percent. After the clay was disposed in the mold, the pore pressure gauge was installed. The sample was placed in water between the upper part of the sample, and the membrane was drawn out through the rubber tube. The pore pressure gauge was set at the specified position by cutting a hole in the side of the mold. The hold was then plugged with a rubber plug to seal the sample. The experimental conditions are given in Table 1.

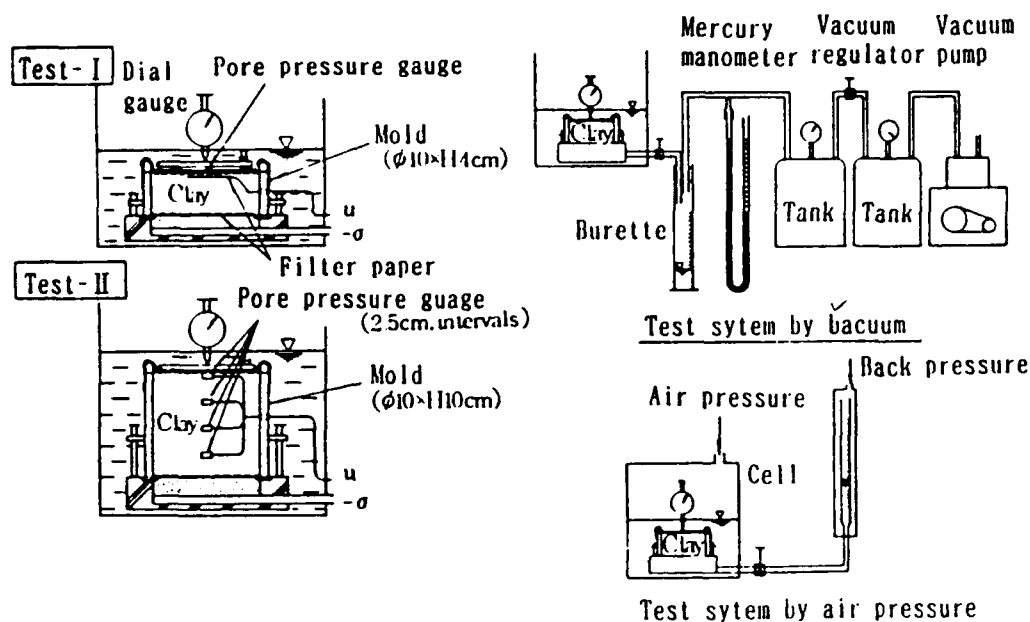


Figure 1. Experimental setup

TABLE 1. EXPERIMENTAL CONDITIONS

Test	$W_o$ (%)	$\sigma$ (Kgf/cm <sup>2</sup> )
I	110	-0.05, -0.1, -0.25, -0.4, -0.8, 0.05, 0.1, 0.2, 0.4, 0.8
II	110	-0.8, 0.8

#### Comparison of One-Dimensional Consolidation by Vacuum and Loading

Figures 2 and 3 show the results of the measurements made on settlement and pore water pressure in Experiment I. When the settlement curves for vacuum consolidation and loading consolidation are compared, both settlement curves are found to be approximately in agreement until the average degree of consolidation reaches 80 to 90 percent, under all loading conditions. When considering the long-term settlement curve obtained with  $|\sigma|$  equal to 0.8 kgf/cm<sup>2</sup>, it is noted that the settlement proceeds linearly on logarithmic coordinates. On the other hand, the measurement results on pore water pressure indicate that the process of dissipation of pore air pressure is exactly the same as the process of propagation of vacuum.

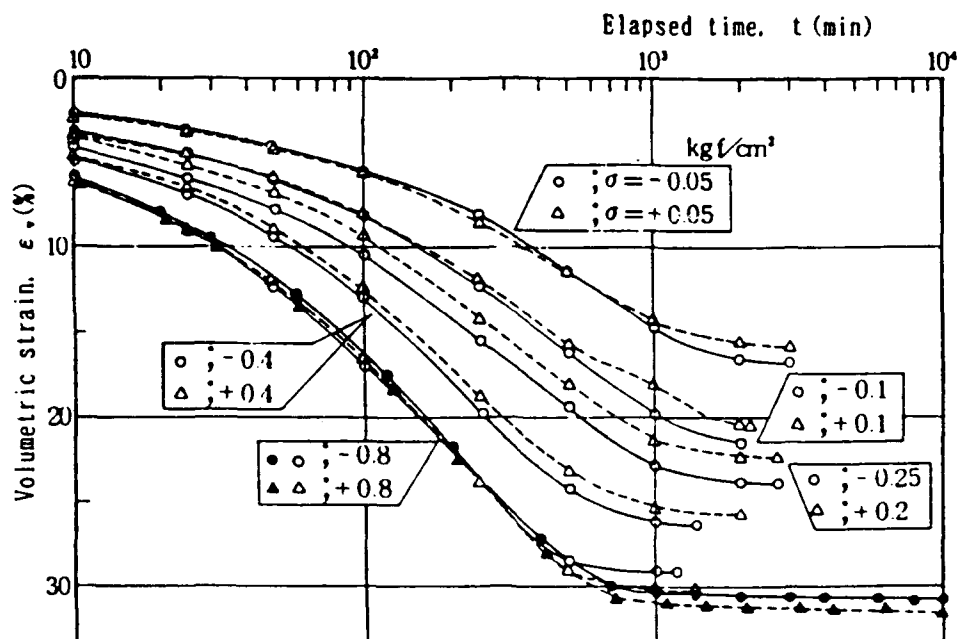


Figure 2. Settlement curves (Experiment I)

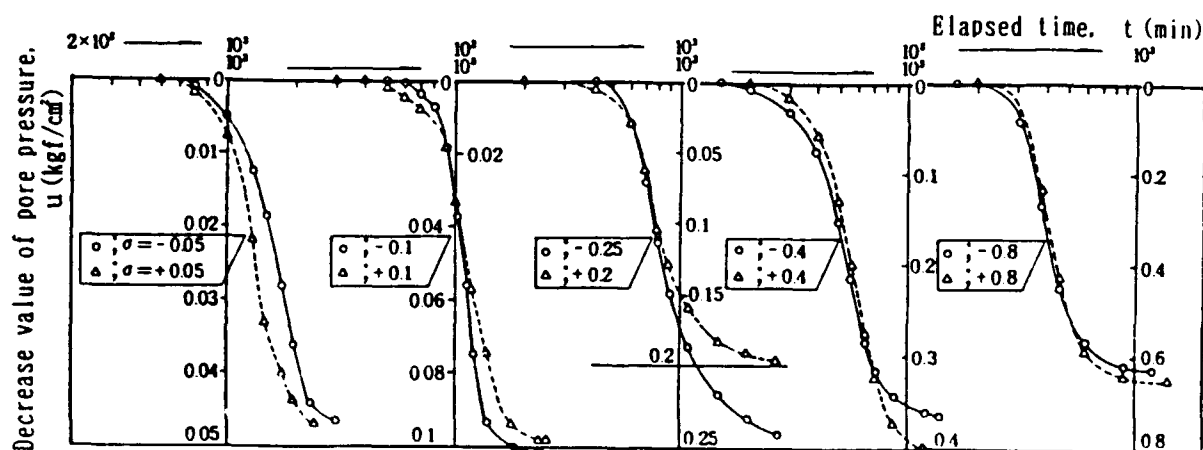


Figure 3. Pore water pressure measurements (Experiment I)

The measurements on settlement and pore water pressure in Experiment II are given in Figure 4. In this figure, the settlement curves for vacuum consolidation and loading consolidation are in very good agreement, and the trends in the pore water pressure are also in fairly good agreement. When examining the measurements on pore water pressure for vacuum consolidation in Experiment II, it is found that the pore water pressure in clay decreases to  $u$  equals  $-0.6 \text{ kgf/cm}^2$ , but then tends to rise when this pressure is reached. The reason is probably because the vacuum causes the dissolved air in the pore water to expand.

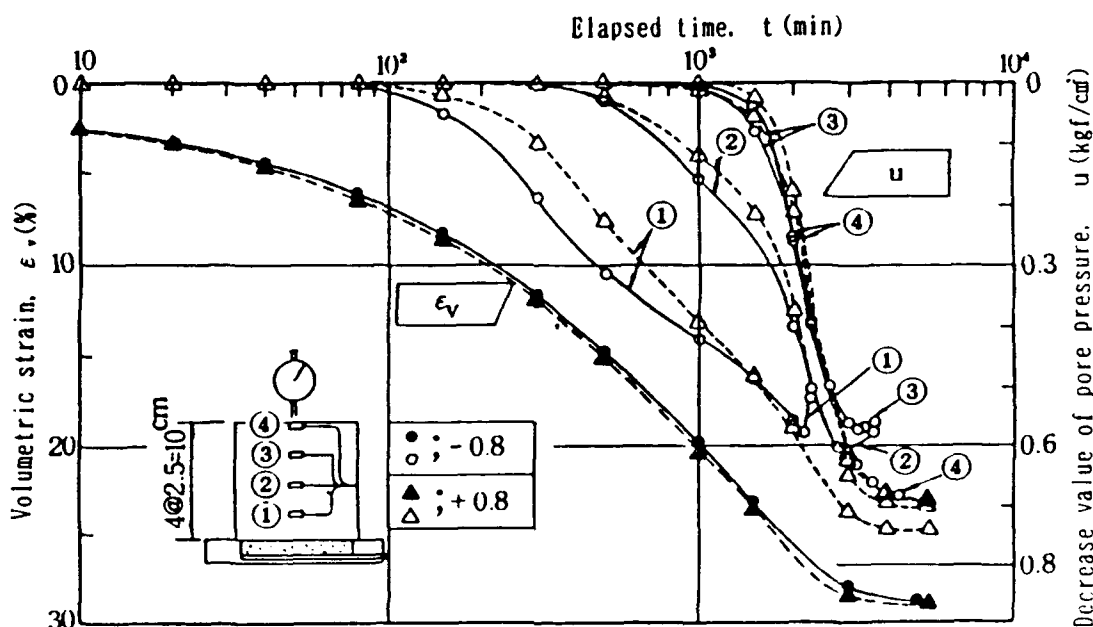


Figure 4. Settlement and pore water pressure measurement (Experimental II)

The results for water content after completion of vacuum consolidation and loading consolidation are given in Figure 5. It is apparent from this figure that the water content and density after consolidation are exactly the same for both methods.

From the above experimental results, it can be concluded that one-dimensional consolidation by vacuum and by loading are identical processes.

On the actual site, real improvement can be expected using a vacuum in the range of  $-0.5$  to  $-0.8$   $\text{kgf/cm}^2$  when applying vacuum consolidation to horizontal drains. For example, the water content after consolidation is  $W = 65$  percent in Figure 5, and a substantial reduction in volume can be expected when a vacuum is applied to clayey soil.

#### IMPROVEMENT OF SOIL IN A LANDFILL MADE BY DISPOSAL OF CLAYEY SOIL DREDGED FROM THE SEA BOTTOM

An onsite experiment with the vacuum consolidation method and horizontal drains was performed in a landfill in Oita Prefecture. This land is extremely soft dredged soil which has been standing for approximately half a year after disposal. In this experiment, 40 drains were laid in the soil, and a vacuum was applied until consolidation was completed.

#### Outline of Experiment

The plan of the experiment site is shown in Figure 6.

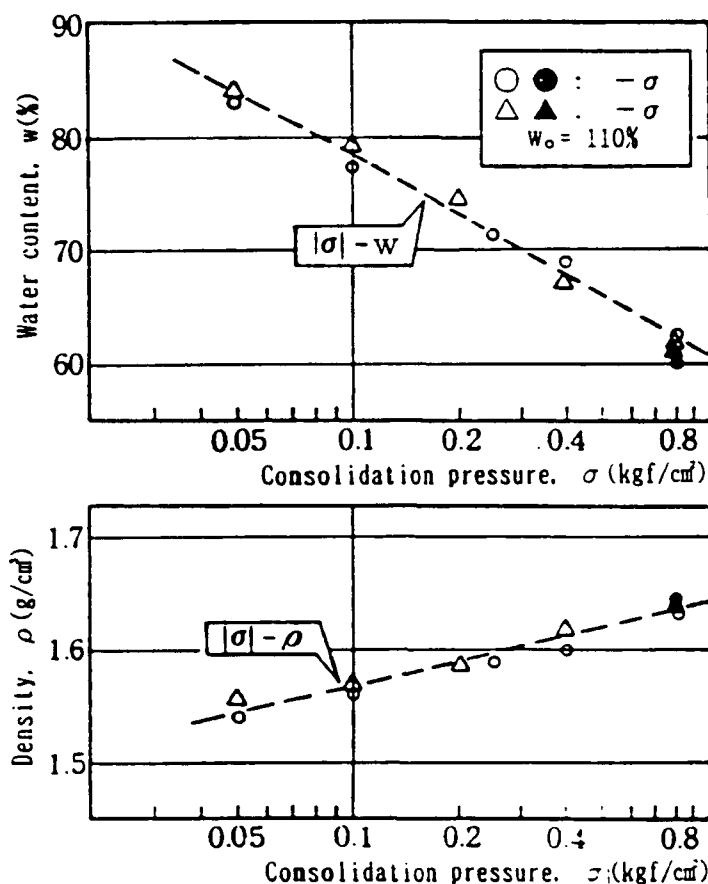


Figure 5. Water content and density after consolidation

The soil improvement area is located approximately 30 m inside the landfill from the central bulkhead. Here, 40 drains (in four levels and 10 rows), each 50 m long, were laid horizontally with 0.7-m horizontal and vertical spacing. The depths of drains were, as indicated in Figure 7, G.L. -1.0 m for the uppermost level, and the surface layer of soil in the improvement area, 65 cm in thickness, was left out of the improvement zone. The surface soil was left out because it was expected that this layer would provide a sealing effect against the vacuum. The drains are the same as those used for conventional vertical drains, with a 10-cm cross section and 3-cm wall thickness. The vacuum was applied continuously for 57 days, and the data shown in Table 2 were collected continuously over this period.

#### Drain Laying Method

The horizontal drain laying system is illustrated in Figure 8. The drain laying system consists of a polystyrene foam barge carrying the drains and the gear which guides the drains to the specified depth. The drains were laid in the sequence below.

- a. With the guide gear fastened to the barge, the drains and drain hoses with caps are connected together. The drain hoses were connected to the anchor pile.

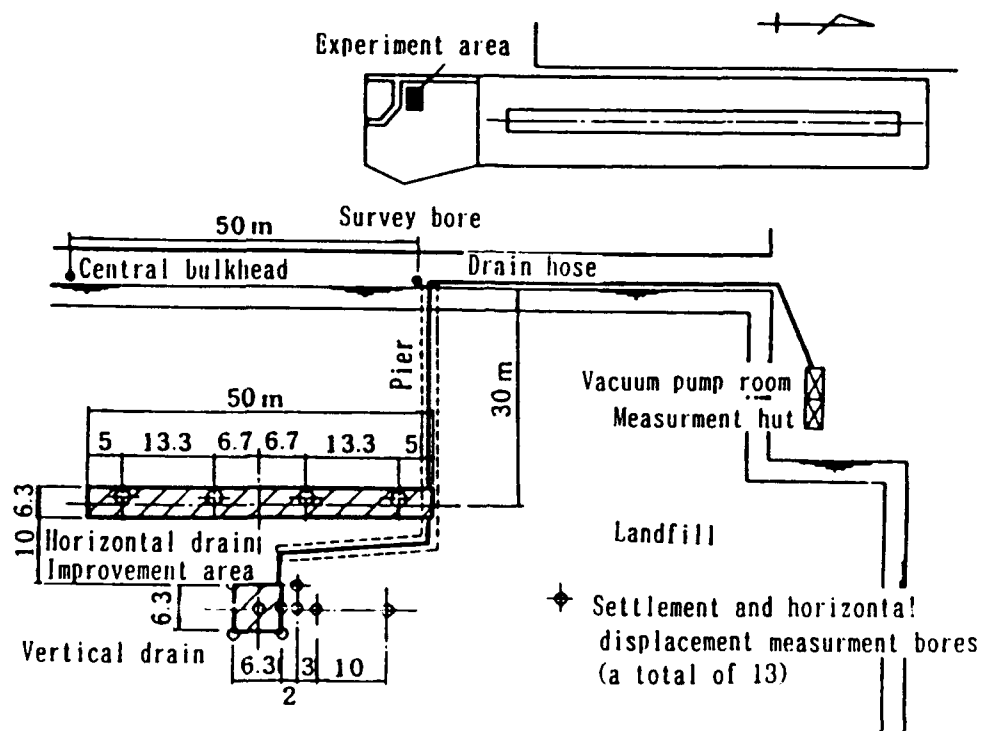


Figure 6. Plan of experiment site

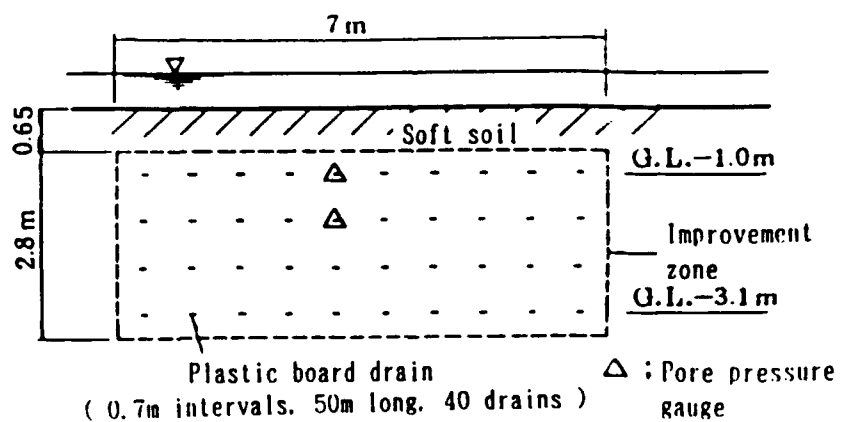


Figure 7. Cross section of installed horizontal drain

TABLE 2. MEASURED DATA

Measured Data	Measurement Point	Measurement Method
• Drain amount	1	Cumulative flow meter
• Working vacuum	1	Pore pressure gauge
• Pore water pressure inside drain	6	Pore pressure gauge
• Settlement	4	Level survey meter
• Horizontal displacement	4	Transit survey

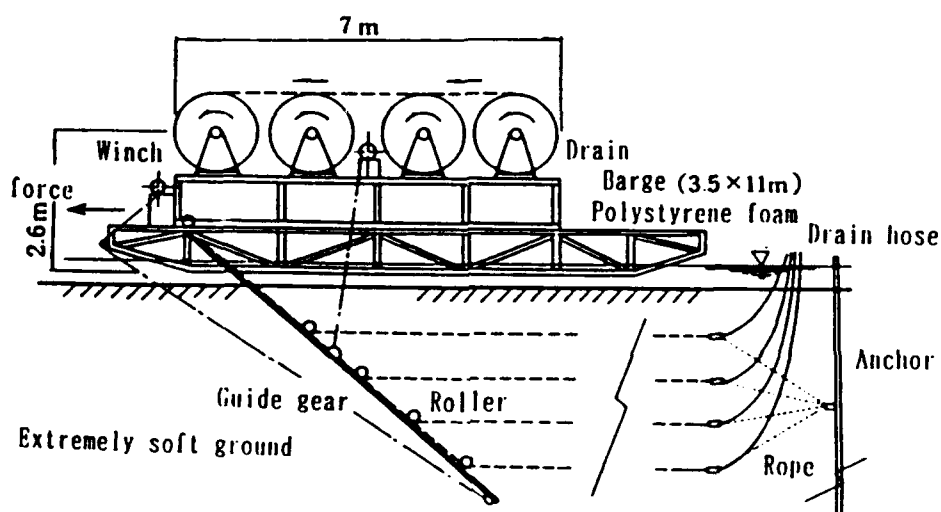


Figure 8. Horizontal drain laying system

- b. The guide gear was driven into the clayey soil by a winch, and at the same time the anchor pole was pushed into the soil. When the guide gear reached the specified angle (45 deg), the guide gear drive was stopped.
- c. With the guide gear buried in the soil, the barge was winched towards the burial point, laying the drains as it moved.
- d. The barge was stopped temporarily at a point where the 45-m sections of drains were laid, the drains were cut to the specified lengths, and the drain ends were sealed.
- e. The barge was again driven in the direction of burial, to complete the laying operation.

One row (four drains) of drains were laid in a single operation, and the operation was repeated 10 times. As the draft of the polystyrene foam barge

was 10 cm, and the water level was 30 cm above the soil surface, the barge was completely afloat. The traction force was approximately 300 kg while the drains were being laid, and the laying operation was not difficult as the ground was extremely soft.

### Vacuum Loading System

The vacuum loading system is illustrated in Figure 9.

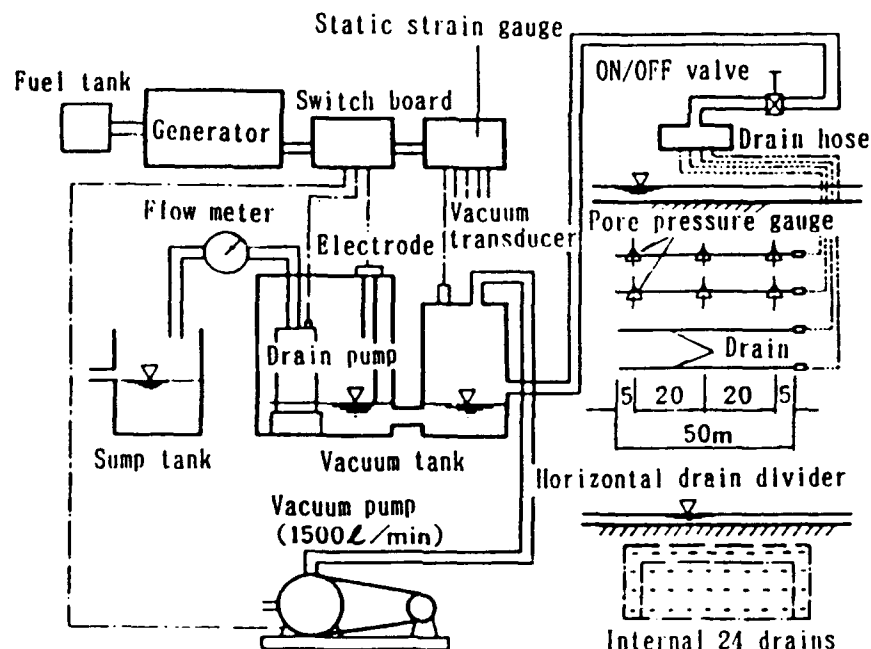


Figure 9. Vacuum loading system

The drain passed through the suction head, and then to the vacuum tank. There was a drain pump in the vacuum tank, which was activated when the water level reaches the upper electrode, automatically draining the water to the sump tank. In route, the drain water passed through the flow meter, and the cumulative flow was recorded.

### Experimental Results and Evaluation

#### Vacuum Versus Drain Speed

The time variations in the vacuum level in the proximity of the vacuum pump, the cumulative volume of drain water, and the drain speed are illustrated in Figure 10. It can be seen from Figure 10 that at first a high vacuum of  $-0.9 \text{ kgf/cm}^2$  was maintained, which decreased with time, reaching  $-0.75 \text{ kgf/cm}^2$  at  $t$  equals 57 days, on which day the experiment was terminated. The reason for this decrease was the rise in temperature of the vacuum pump cooling water, which reduced the pump suction efficiency.

The cumulative volume of drain water was  $510 \text{ m}^3$  at  $t$  equals 57 days. The drain speed for all 40 drains ( $q$ ) was  $q = 40 \text{ l/min}$  immediately after the vacuum was applied, but decreased as consolidation progressed and fell to

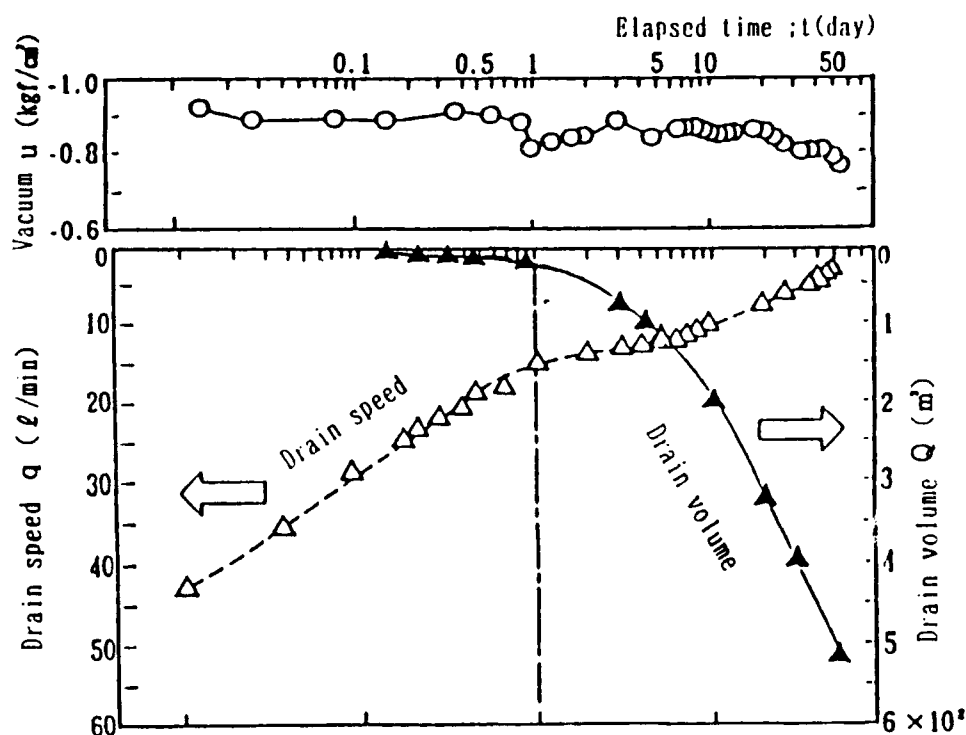


Figure 10. Vacuum, cumulative drain volume, and drain speed

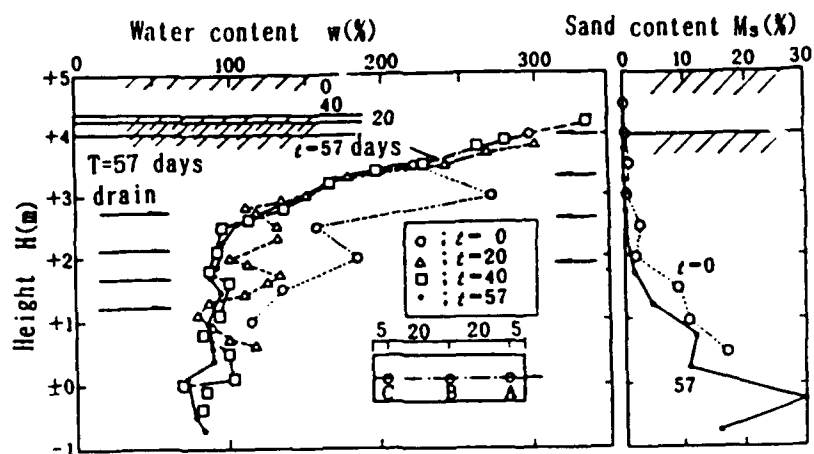
approximately one half the initial value after 1 day. At  $t = 57$  days when the experiment was completed,  $q$  equaled 3 ℓ/min, exhibiting a drastic decrease.

#### Variation in the Water Content

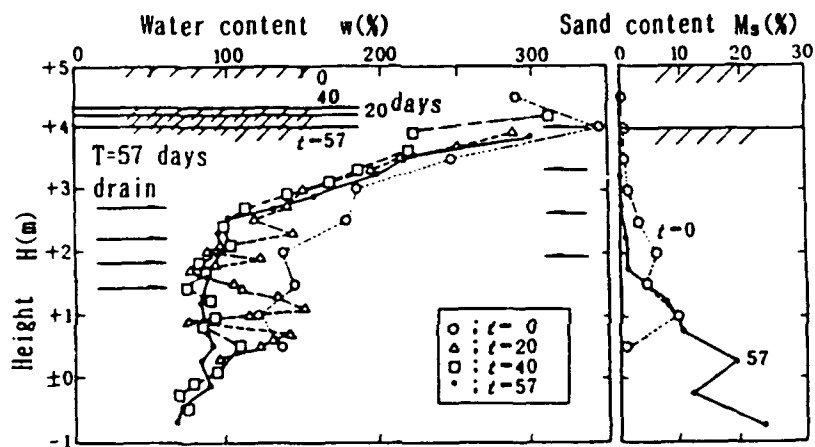
Variation in the water content with time at the center of the improvement zone is illustrated in Figure 11. A preliminary survey before the experiment indicated that the water content at the surface layer was  $w = 200$  to 300 percent decreasing gradually as the depth increased. This decrease can be accounted for by the larger sand content with depth and the process of consolidation under the weight of the soil itself.

The data at  $t = 20$  days indicated that the improvement zone was mixed, with areas where the water content had decreased to around 90 percent, and some areas were still as high as 150 percent. This indicated that the water content decreased near the drains but still was high in areas between the drains, and that consolidation was still going on at  $t = 20$  days. At  $t = 40$  days, the variation in water content almost disappeared, and the water content was almost uniformly distributed at 90 to 100 percent everywhere at  $t = 57$  days.

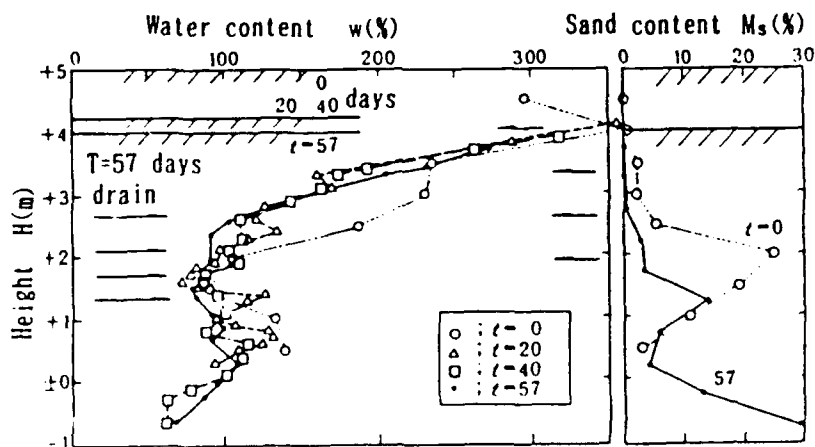
When the drain depths were studied at  $t = 57$  days, it was found that the first-level drains had sunk approximately 1.3 m from the initial laying depth. The distance between drains was approximately 60 cm between the first level and the second level, and approximately 40 cm between the second level and the third level and also between the third and fourth. In vacuum



a. Point A



b. Point B



c. Point C

Figure 11. Variation in water content with time

consolidation, the vacuum causes the clay to concentrate around the drains. This tendency caused the clay in the surface layer to move to the periphery of the first level, allowing the second level to drain. As a result, the interdrain distance at this level decreased by only 10 cm.

The water content was  $w = 90$  percent or so in the layer between the soil surface and the first-level drain, and the water content increased almost linearly as the depth decreased. The first-level drains were laid at a depth of G.L.  $b = 1.0$  m initially, but this depth changed to G.L.  $= -1.3$  m after  $t = 57$  days. The reason that the thickness of the surface soil increased was that the clay from the surrounding areas flowed into the upper layer of the improvement zones.

#### Settlement Curve

The settlement curve is given in Figure 12. This figure indicates that there was no difference in settlement at the proximity of the drain hose and at the tip of the drain.

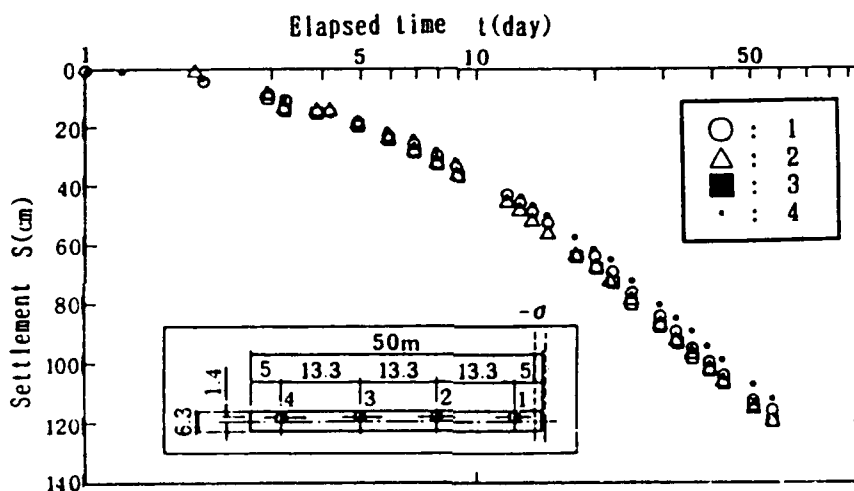


Figure 12. Settlement curve

By assuming that the initial water content of the clay before improvement was  $w_o = 200$  percent, and obtaining the consolidation strain  $\epsilon_f$  by the following equation, the result is  $\epsilon_f = 44$  percent.

$$\epsilon_f = \frac{e_o - e_f}{1 + e_o}$$

where

$$\begin{aligned} \text{Initial void ratio: } e_o &= G_s \times w_o \approx 5.3 \\ e_f &\approx 2.5 w_f \approx 94\% \\ &(\text{specific gravity, } G_s = 2.65) \end{aligned}$$

In considering the consolidation speed of extremely soft clayey soil, the change in layer thickness cannot be neglected as the consolidation process is accompanied by a large strain. Here, Barron's consolidation theory was applied as an approximation of the consolidation process with horizontal drains, and the effect examined. The result is indicated in Figure 13. In this figure, the measured consolidation curve approaches the theoretical curve with drain distance  $d_{eo} = 70$  cm at the final stage of consolidation and the curve of  $d_{eo} = 40$  cm at the final stage of consolidation. If the consolidation speed is proportional to the square of the layer thickness, the theoretical drain distance can be obtained by the following equation:

$$\bar{d}_e = [(d_{eo}^2 + d_{ef}^2)/2]^{1/2}$$

When the theoretical curve is plotted in the same figure, the curve shown by the broken line is obtained. When this theoretical curve is compared with the measured curve, they are found to be in good agreement on the average. Then it can be concluded that the method based on Barron's consolidation theory is applicable to the actual consolidation process with horizontal drains.

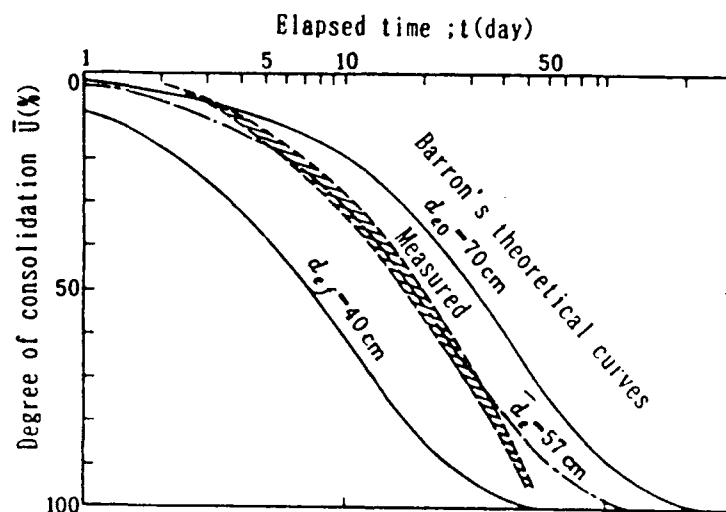


Figure 13. Comparison of measured versus theoretical curves

The results of unconfined compression tests on the soil after consolidation are presented in Figure 14. The average strength after improvement was  $q_u = 0.125$  kgf/cm<sup>2</sup>.

#### IMPROVEMENT OF WASTE DISPOSAL SITE FOR SLURRY

A project was conducted to improve the soil at a waste disposal site for slurry (soda ash) in Yamaguchi Prefecture.

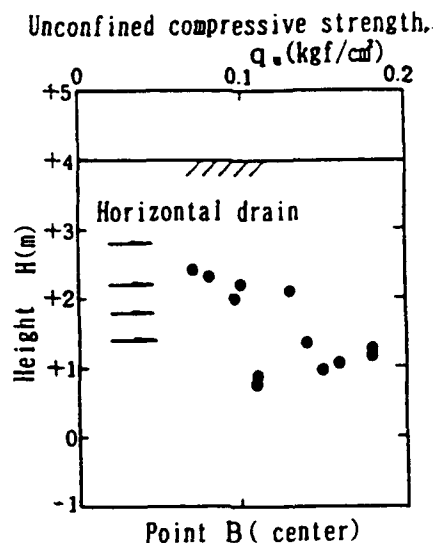


Figure 14. Unconfined compressive strength after improvement

#### Outline of Improvement Project

The site where the improvement project was carried out is illustrated in Figure 15. The total improvement area was about 40,000 m<sup>2</sup>. The drains were laid in three levels and in square cross sections, which were each separated by a distance of 1.5 m. The total length of the drains laid amounted to approximately 80,000 m. Three types of drains were used: 10 cm wide × 3 mm thick, 10 cm wide × 6 mm thick, and 15 cm wide × 12 mm thick. In this project, improvement was performed with surface water present all the time.

#### Initial Soil Condition and Soil Characteristics

The soil characteristics of the soda ash layer before improvement are presented in Figure 16. The water content was 500 to 600 percent at the surface, decreasing with depth. Electrical cone penetration tests were conducted, and it was found that the penetration resistance at the surface was very low. According to the consolidation tests in soda ash, the coefficient of consolidation in the normal consolidation zone was  $C_v = 500$  cm<sup>2</sup>/day, and the coefficient of volume compressibility  $M_v = 0.2 p^{-0.92}$  cm<sup>2</sup>/kgf ( $p$  = effective stress).

#### Method of Laying Drains

The drains were laid by an improved type of laying barge. The drain laying procedure was the same as described in Figure 8.

The laying procedure is illustrated in Figure 17. Winches were installed on the banks on both sides to pull the laying barge forward and backward. A bulldozer was stationed on the line of laying and was used as an

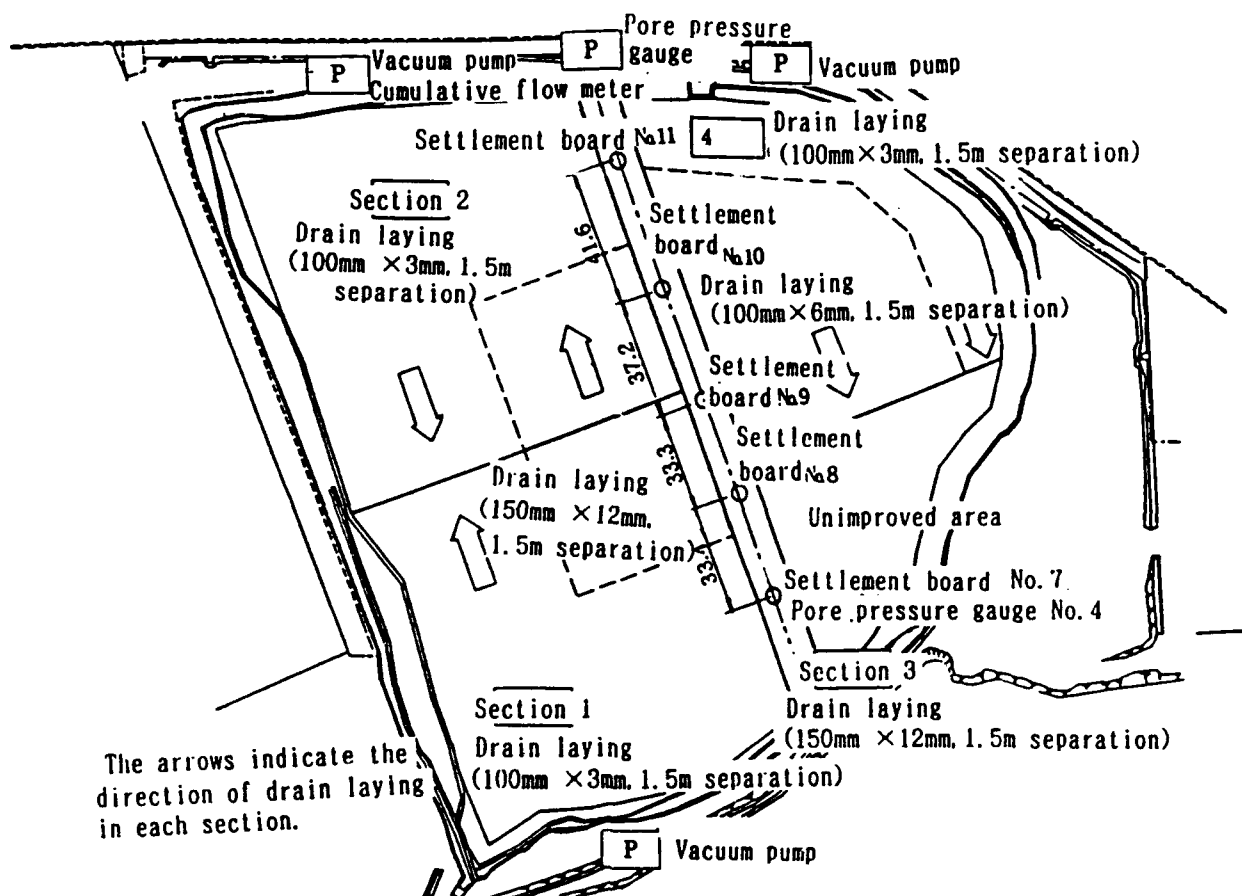


Figure 15. Project plan for improvement of waste disposal site for slurry

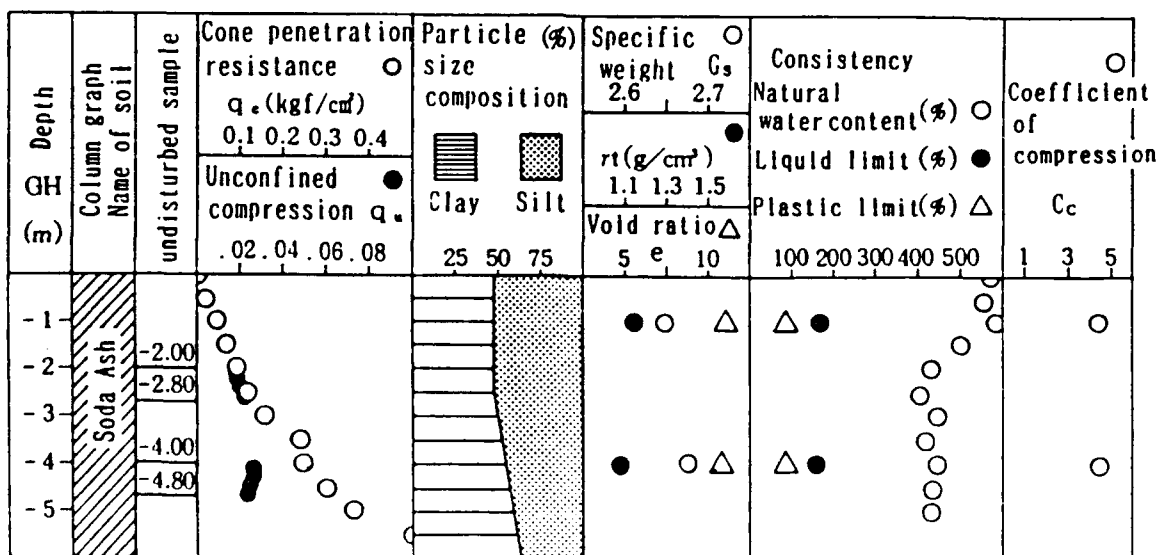


Figure 16. Soil characteristics of soda ash layer

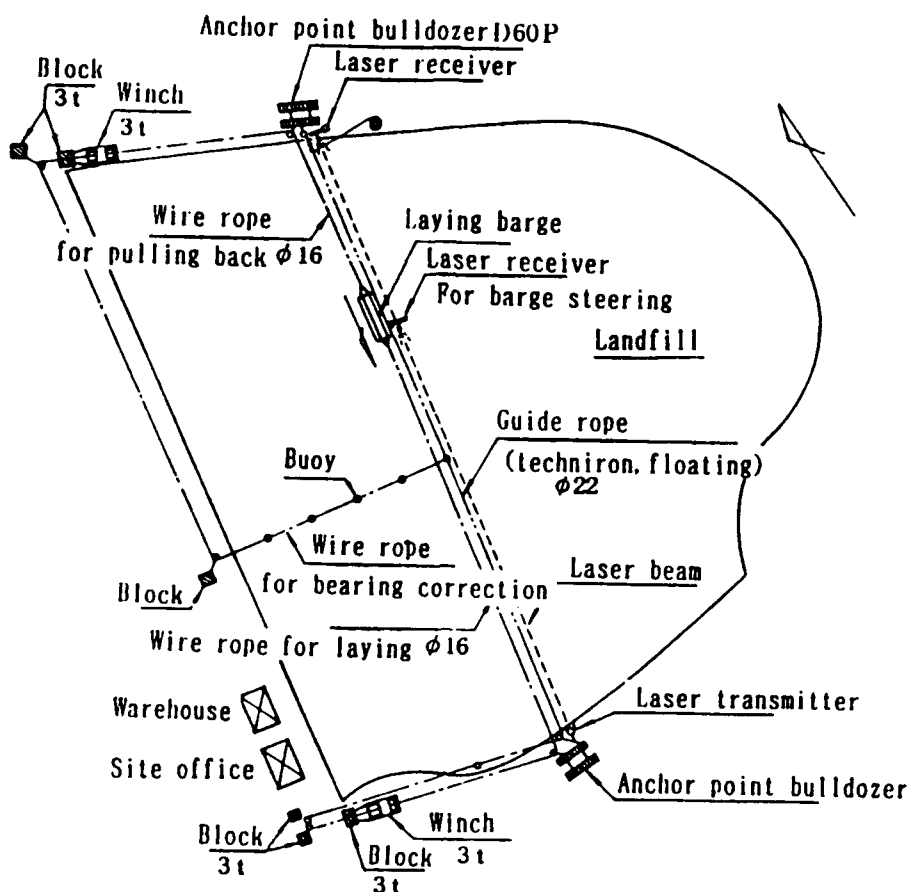


Figure 17. Barge operation

anchor point. This bulldozer also helped to improve the operational efficiency of the drain laying. As a guide to allow drains to be laid on a straight line, a floating rope was strung parallel to the direction of laying, and the laying barge moved along this rope.

#### Experimental Results and Evaluation

##### Relation Between Soil Strength and Traction Force of Barge

The relation between the cohesion of the soil and the traction required to lay the drains is illustrated in Figure 18. The following relation between the cohesion  $C$  and the traction force  $T$  had been obtained.

$$T = 4.0C + 0.5 \quad (T: \text{tf}, C: \text{tf/m}^2)$$

This cohesion force has been obtained by the relation  $c = q_c/10$  from the cone penetration resistance tests.

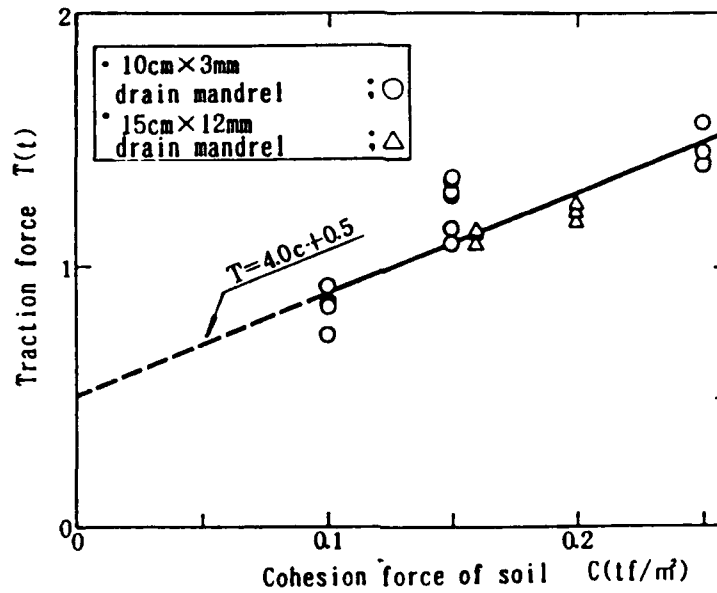


Figure 18. Relation between soil strength and traction force of laying barge

#### Drain Laying Time

The time spent in laying drains of 10 cm wide x 3 mm thick for lengths of approximately 100 m are illustrated in Figure 19. The time required to lay a single row of drains was approximately 32 min.

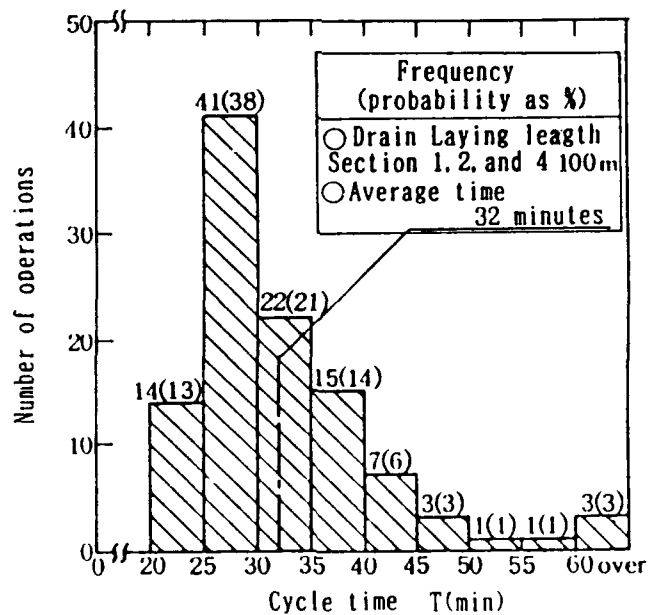


Figure 19. Drain laying time

## Measurement of Settlement and Volume of Drain Water

The time variations in the working vacuum, settlement, volume of drain water, drain speed, and pore water pressure in Section 3 of the plan area (Figure 15) are illustrated in Figure 20. Drains that were 15 cm wide  $\times$  12 mm thick were laid in approximately 200-m lengths. According to the data on settlement in Figure 20, there was little delay in settlement between No. 11 point, which was the nearest to the pump, and No. 7 point, which was the farthest, indicating that the whole area of Section 3 settled uniformly.

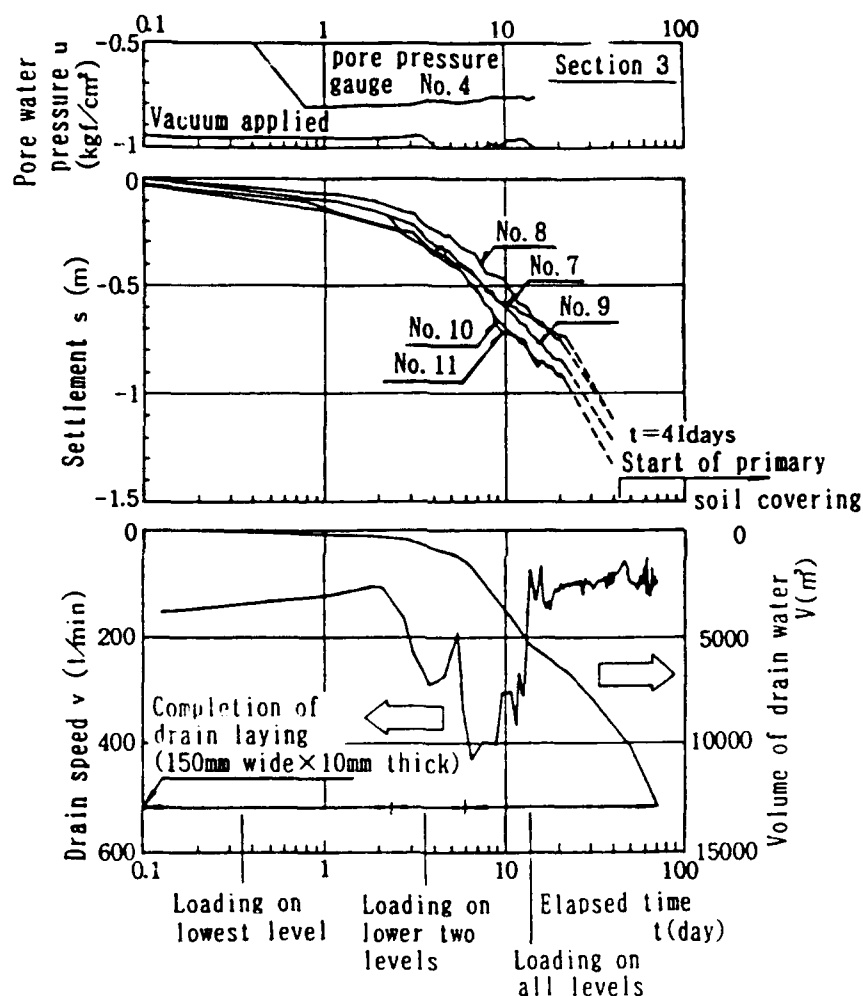


Figure 20. Measurement of settlement and volume of drain water

When the volume of drain water was observed, the total volume was approximately  $V_1 = 8,000 \text{ m}^3$  at the time when settlement reached approximately 1 m. On the other hand, when the empty space created by settlement was calculated,  $V_2 = 3,000 \text{ m}^3$  (size of an area 15 m in width  $\times$  200 m in length  $\times$  1-m decrease in height). Therefore, the seepage of water from the soil surface was  $5,000 \text{ m}^3$ , which was considerably larger than the water squeezed out of the soil, probably because the soil surface was dry and there were invisible cracks. The fact that settlement proceeded uniformly despite the large

amount of seepage water indicates that the drain capacity of the 15-cm-wide × 12-mm-thick drain material was sufficient even with the presence of a large amount of surface water.

Considering the variation in drain speed with time, the drain speed immediately increased when the vacuum was applied to the drains and then gradually decreased with the consolidation time.

#### Selection Through Drain Material

The volume of drain water passed by each type of drain is presented in Table 3. The time of 30 days in the table is the time required for the average degree of consolidation to reach approximately 80 percent. The average volume of water drained per one drain per day can be calculated from the following equation:

$$q = Q/(t \times n)$$

where  $Q$  is the volume of water drained in 30 days,  $t$  is 30 days, and  $n$  is the number of drains.

TABLE 3. MEASUREMENT OF DRAIN CAPACITY

Symbol	Type and number of drain material $n$	Empty cross section of drain material $s$	Volume drained after 30days $Q$	Average flow for 30 days $q=Q/(tn)$	Studied by Project Section
●	10cmwide×3mmthick 204drain. 100mlong	1 cm <sup>2</sup>	700 m <sup>3</sup>	1.14 m <sup>3</sup> /day/drain	Section 1
○	10cmwide×6mmthick 204drain. 100mlong	5 cm <sup>2</sup>	11,000 m <sup>3</sup>	2.26 m <sup>3</sup> /day/drain	Section 4
△	15cmwide×12mmthick 30drain. 200mlong	12 cm <sup>2</sup>	8,000 m <sup>3</sup>	8.89 m <sup>3</sup> /day/drain	Section 3
□	10cmwide×3mmthick 40drain. 50mlong	1 cm <sup>2</sup>	370 m <sup>3</sup>	0.31 m <sup>3</sup> /day/drain	Oita Experiment

The relation between the average drain capacity and the empty cross section of the drain material is summarized in Figure 21.

It can be seen from this figure that the maximum drainage capacity increases rapidly with the empty cross section. Therefore, when an attempt is made to improve clayey soil by applying a vacuum, drain material must be selected so that the designed drain capacity is on the right side of the broken line in Figure 21.

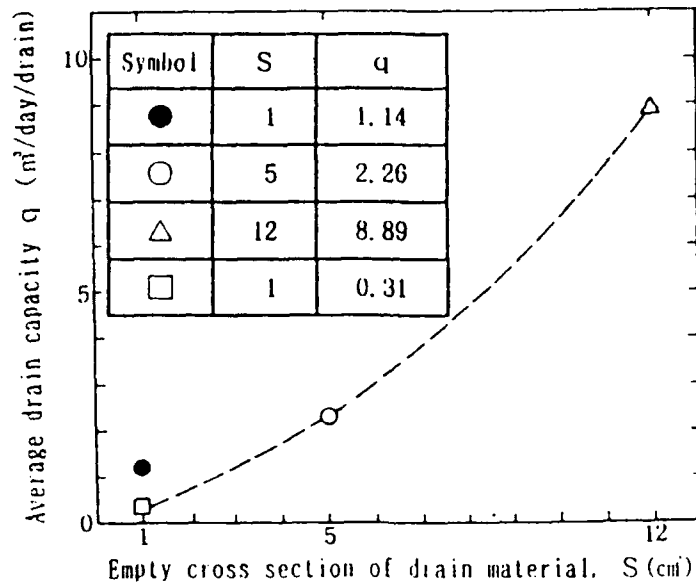


Figure 21. Relation between empty cross section of drain material and average drain capacity

#### Soil Improvement Performance

- a. Change in water content. Typical changes in the water content are illustrated in Figure 22. The water content was  $w_o = 500$  to 600 percent at the soil surface and 300 to 400 percent below the -4-m depth before improvement. In contrast, by the time settlement had reached 85 m (but not completed),  $w = 400$  percent at the surface and 200 to 300 percent at depths below -4 m, indicating a marked reduction in the water content after consolidation.
- b. Penetration resistance. Results of cone penetration tests conducted before and after soil improvement are presented in Figure 23. The tests after improvement indicated that there remained a layer having a penetration resistance of  $q_c < 0.05 \text{ kgf/cm}^2$  from the soil surface to a depth of around 1.0 m, while  $q_c = 0.5 \text{ kgf/cm}^2$  was obtained in the improved soil. The reason that a low resistance layer remained near the surface was that water seeped from the surface to the drain, as the soil surface was not sealed by sheets.

#### CONCLUSIONS

In this report, the vacuum consolidation method employing horizontal drains has been discussed as a means of improving very soft soil. The conclusions reached are as follows:

- a. When a vacuum of around  $-0.5 \text{ kgf/cm}^2$  was applied to clay in Tokyo Harbor, the water content was reduced to approximately 65 percent. Based on this performance, it was concluded that the vacuum consolidation method has a substantial effect in reducing the volume of very soft clayey soil.

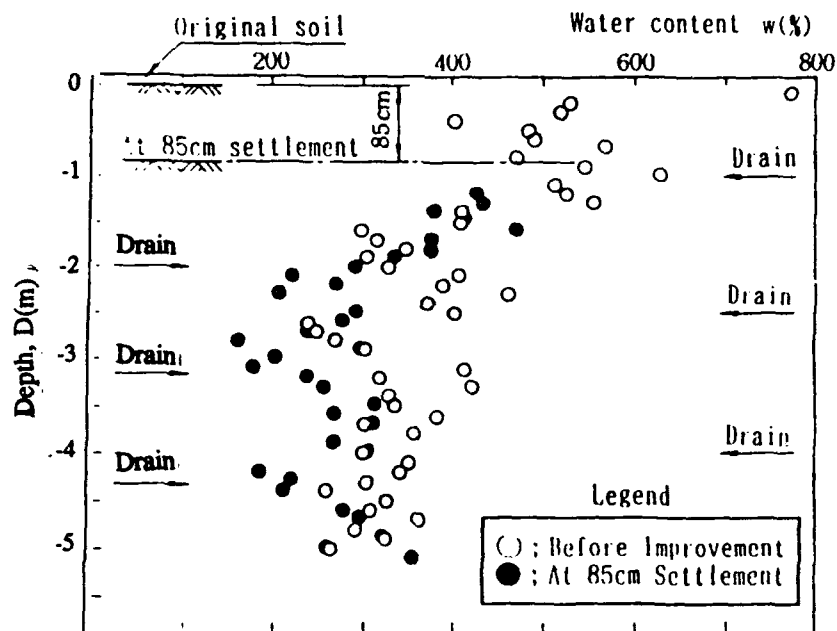


Figure 22. Change in water content distribution

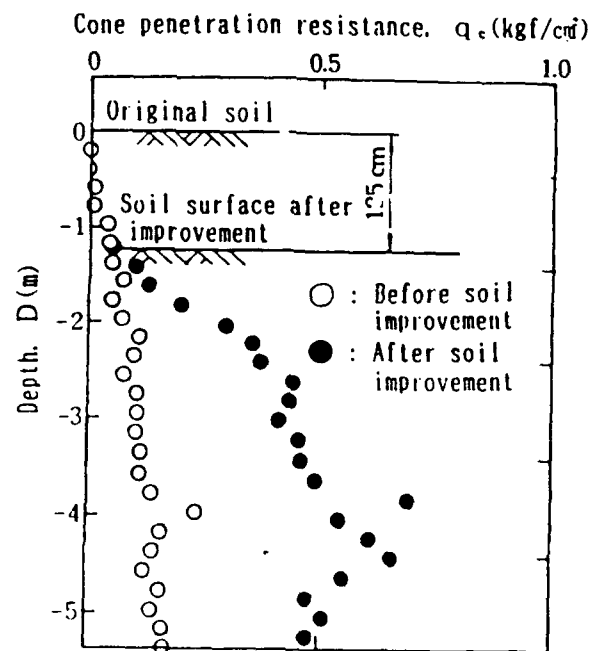


Figure 23. Distribution of penetration resistance before and after improvement

- b. It was verified by experiment that laying horizontal drains in soil is relatively easy.
- c. The experiment conducted on a landfill made of dredged clayey soil indicated that the initial water content of  $w = 200$  to 300 percent in clay was reduced uniformly to 90 to 100 percent after improvement. The average soil strength after improvement was  $q_u = 0.125 \text{ kgf/cm}^2$ .
- d. The experiment conducted on a waste disposal site for slurry indicated that (1) application of a vacuum through 15-cm-wide  $\times$  12-mm-thick drains laid for approximately 200 m resulted in uniform settlement of the improvement area, and (2) the water content measured before improvement was 300 to 600 percent but was reduced to 200 to 400 percent after improvement.

At the site, experiments were conducted with surface water over the soil. A low-strength, clayey soil layer remained from the soil surface to a depth of approximately 1.0 m. It is necessary to develop a method by which the surface layer can also be improved.

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# TOXICOLOGICAL ASSESSMENT OF HAZARDOUS WASTES

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**AD-P006 468**

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## ABSTRACT

Section 121 of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (SUPERFUND) calls for hazardous waste site remediations which permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants. Traditional engineering technology has concentrated on reduction in volume and mobility as assessed by chemical and geophysical measures. It was assumed that accomplishment of volume and mobility reduction would lead to reductions in toxicity. Environmental scientists long have argued that this assumption might not be the case. However, lack of consensus on how complex hazardous waste mixtures should be measured toxicologically hampered integrated assessments. Therefore, a battery of aquatic and terrestrial bioassays was assembled and evaluated comparatively against several chemicals and waste site chemical mixtures. The bioassays were then applied to a mobility reduction demonstration to assess its overall chemical, physical, and biological performance. Results indicated that, while the primary objective of mobility reduction seemed to be achieved, undesirable secondary effects (toxicity) were introduced. These trade-offs must be considered in the holistic sense when remediation measures are being implemented.

## INTRODUCTION

### Legislation

Public concern for environmental and public health effects resulting from the disposal of industrial and agricultural waste mixtures led to the development and passage of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. The purpose of this act, commonly known as SUPERFUND, is to remediate hazardous waste sites in ways that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants.

**92-10788**



## Traditional Approaches

### Chemical Measures

The traditional approach to the hazardous waste site problem assessment has been to make a series of chemical analyses for priority pollutants (129 consent decree chemicals) and apply these concentrations against existing chemical criteria or standards (Keith and Telliard 1979). The individual chemical exceedances might then be taken collectively to assess relative risks at a site. A major concern with this approach is that the priority pollutant list consists primarily of human health carcinogens and mutagens, i.e., long-term bioaccumulating chemical effects rather than short-term toxic effects.

### Shortcomings

Because of the above approach, ecological considerations are minimized relative to human health concerns. Other shortcomings to the chemical-by-chemical criteria assessment approach include:

- Inadequate databases for developing sound criteria for many chemicals.
- Lack of criteria values for many chemicals encountered at hazardous waste sites.
- Criteria based on laboratory studies underprotect or overprotect when applied to the field.
- Most criteria numbers give only limited consideration to environmental variability.
- Criteria numbers were not meant to be used additively.
- Soil and sediment criteria have been slow to develop.

Figure 1 illustrates the difficulty in estimating environmental toxicity based on chemical analysis of site samples. The figure represents a typical GC/MS scan of a waste site sediment leachate in which four priority pollutants and nine nonpriority pollutants can be identified. Fourteen other organic substances remain as "unknowns." Among the four identifiable priority pollutants, an environmental criterion exists only for phenol (3.4 mg/l). Thus, the determination of environmental toxicity of this sample based on its chemistry is nearly impossible.

### Advantages of Bioassays

One way to offset problems associated with the use of chemical measures alone is to supplement them with environmental toxicology tests (bioassays). These tests provide a more direct measure of environmentally relevant toxicity (Roop and Hunsaker 1985). Additional advantages of these test are that they

- Integrate the effects of all environmental variables and chemicals.

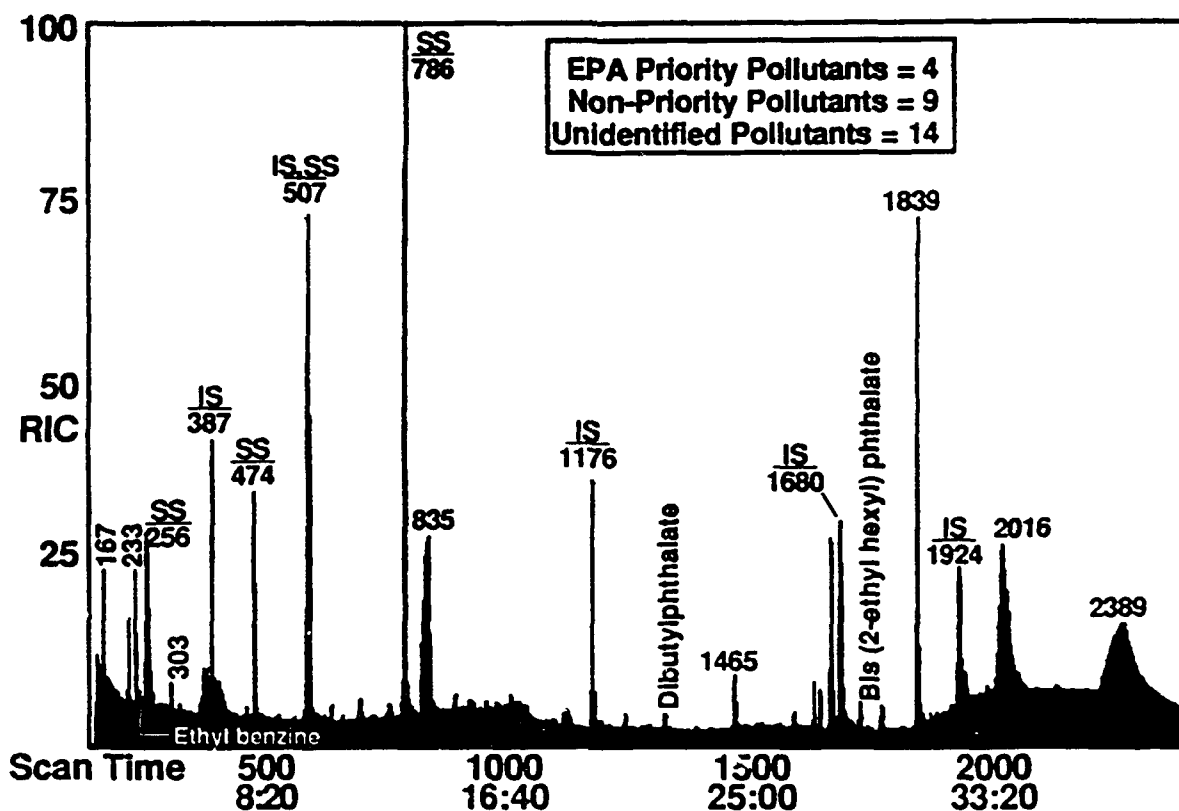


Figure 1. A GC/MS scan of a sediment leachate from the Western Processing Site (Kent, Washington) showing peaks for priority and nonpriority organic pollutants

- Provide a means of screening a wide variety of samples for acute toxicity.
- Help identify media and organisms at greatest risk.
- Offer a means of directing chemical analyses.

This is not to say that short-term bioassays are without limitations. Among the limitations are that they do not provide bioaccumulation factors; they do not identify carcinogenic, mutagenic, or teratogenic effects; and they are not chemical specific and thus cannot replace chemical analyses per se. The advantages tend to outweigh disadvantages, but lack of consensus on which tests to use and how to apply them has hindered their general application. Therefore, an acceptable approach had to be developed.

#### APPROACH

##### Selection of Tests

Figure 2 shows a schematic diagram of the overall (single chemical through site application) approach to the problem. Initially, the need was identified for a rapid, off-the-shelf method to assess relative toxicity of complex waste mixtures at hazardous waste sites. A technical group met to

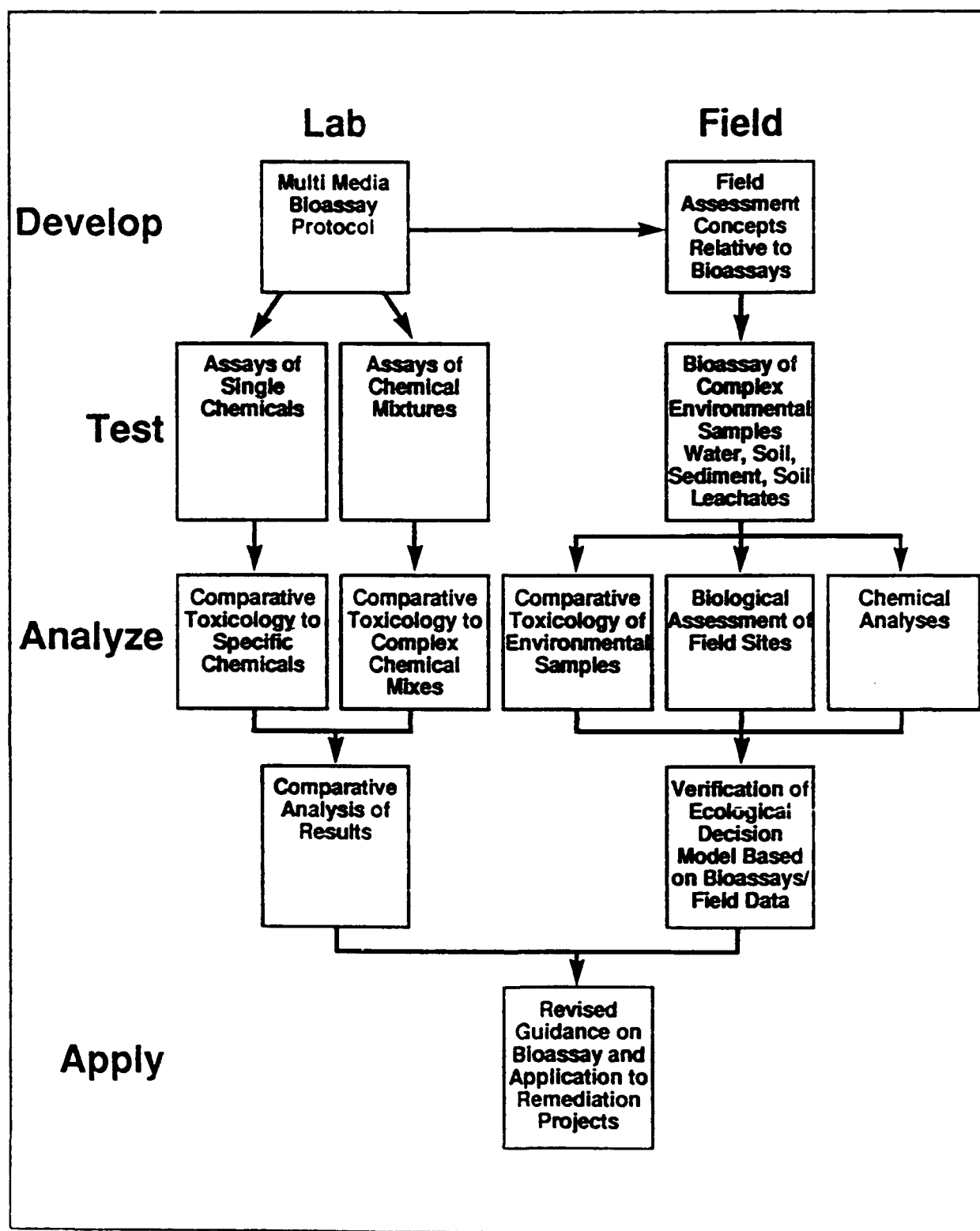


Figure 2. Schematic of the approach

discuss the tests that would most likely serve this need. Test species were selected on the basis of available data, chemical sensitivity, ease of laboratory culture, and types of organisms representing various compartments of the ecosystem. The tests selected included seed germination/root elongation (lettuce, *Lactuca sativa* L.), earthworms (*Eisenia andrei*), algae (*Selenastrum capricornutum*), daphnia (*Daphnia magna*), fathead minnow (*Pimephales promelas*), and Microtox (*Photobacterium phosphoreum*). The latter test is a commercial one (Beckman Instruments, Inc. 1982), but mention of this or any other commercial product names does not constitute endorsement by the US Environmental Protection Agency. The test battery was designed to screen for relative acute and short-term chronic (Algae Test) toxicity in surface water, groundwater, soil, and sediment elutriate.

Danials (1981) and Peterson et al. (1989) have shown that sodium acetate and acetic acid extractants increase sample toxicity. Therefore, it was determined that soil elutriates should be prepared using deionized water. Water was chosen as a conservative, natural leach medium that introduced no additional toxicity to the sample. The pH of deionized water is near neutrality, thus approximating that of nonacidic rainfall. Soil samples were sieved through 0.25-in. hardware cloth prior to eluting. Water as well as soil and soil/sediment eluates were adjusted, when necessary, according to Miller et al. (1978) and Greene (unpublished data, 1984, USEPA) to comply with the test organisms' known pH tolerances. Soil eluates were prepared by mixing 1.0 kg of solid waste (soil) sample with 4.0 l of deionized water. The mixtures, each contained in a 10-l cubitainer, were shaken at 100 rpm for 24 hr at a temperature of  $24^{\circ} \pm 2^{\circ} \text{C}$  (later modified so the soil mixture was placed into 1,500-ml glass vessels placed in a rotary extractor and mixed end-over-end at 30 rpm for 48 hr). The waste/water mixtures were then centrifuged in 300-ml polycarbonate bottles for 10 min at 10,000 rpm and filtered through 0.45- $\mu$  membrane filters prior to assay.

While it is recognized that sample manipulation of this type will compromise absolute toxicity (usually reduces toxicity with metals as pH is adjusted upward, but less clear with organics), our primary objective was to assess the relative, comparative toxicity to different test organisms across a broad spectrum of waste types. Thus, all test organisms were exposed to sample material that had been prepared in exactly the same way. Fathead minnow tests were conducted on only a limited number of samples. The procedures described above constituted the "Protocol for Bioassessment of Hazardous Waste Sites" (Porcella 1983). The protocol was subsequently tested against single chemicals, mixtures of chemicals, and actual waste site samples containing various combinations of chemicals. The purpose was to make recommendations concerning the appropriateness of specific test types and to revise the test protocols.

#### Comparative Toxicology

The graded comparative toxicological assessments allowed us to determine how tests performed with various groups of chemicals, to establish the relative sensitivity of each test species, and to provide a logical sense of confidence that the test battery would detect a broad spectrum of contaminants under varying conditions. Thus, when it came to actual complex hazardous waste site toxicity, we could be reasonably sure that the test battery

responses were true indications of the relative, integrated (all chemicals and environmental variables) environmental toxicity.

The EC<sub>50</sub> or LC<sub>50</sub> toxicities were reported as a percentage of the parent sample material (water, soil, sediment elutriate). Thus, the lower the EC<sub>50</sub>/LC<sub>50</sub>, the greater the toxicity of the sample.

#### Application to Remediation Measures

The bioassessment protocol was used to help evaluate the environmental effects of three soil stabilization and one vitrification procedure at the Western Processing Site near Kent, Washington. The untreated soil and stabilized products were subjected to a series of physical, biological, and chemical performance tests. The commercial treatment procedures are proprietary so the chemical formulation or composition is not revealed. Therefore, the only way to know their composition was to chemically characterize them. The only reasonable way to know whether they exhibited potential environmental toxicity was to conduct bioassays. Experience with the above factors would eventually be used to revise the "1983 Bioassessment Protocol."

### RESULTS AND DISCUSSION

Miller et al. (1985) reported the results of single chemical, complex chemical mixture, and hazardous waste site sample exposure of test organisms in the Porcella (1983) "Protocol for Bioassessment of Hazardous Waste Sites." The EC<sub>50</sub>/LC<sub>50</sub> response values for each of the chemicals investigated were calculated by linear regression analysis of dose/response data. Specific EC<sub>50</sub> chemical concentrations were reported as average values obtained from replicate tests conducted with each test organism. Results are summarized below.

#### Single Chemicals

Tests were conducted with the metals copper, cadmium, and zinc. The individual chemical test results are aggregated in Table 1 to demonstrate their relative toxicity and rank ordering among organisms of the Test Protocol. Algae and *Daphnia* were the most sensitive to these metals. They were followed in descending order by Microtox, seed germination, and earthworms.

Two herbicides, 2,4-D acid, and Esteron 99 (a commercial formulation 2,4-D acid), were tested. Aggregates of the EC<sub>50</sub> responses were obtained for seed germination/root elongation tests at less than 0.17 mg/l (Table 2). Algae, however, were more than 300 times less sensitive than the seed germination test. This is most likely due to the fact that 2,4-D is an auxin analog, which stimulates destructive growth in higher plants. Algae do not have auxin growth regulation, but react to inhibition of the photosynthesis energy transport process. Thus, the difference in response between the seed germination and algae tests is both biologically plausible and predictable. The seed germination and algae responses were followed in descending order by Microtox, *Daphnia*, and earthworms. Thus, the rank order of sensitivity for herbicides differs markedly from that of the metals. It appears that one might eventually gain insight to the kind of contaminant that is responsible for producing a given toxicity when a test battery of organisms is used. That information might help direct chemical analysis where toxicity is deemed a problem.

TABLE 1. EC<sub>50</sub> TOXICITY VALUES FOR HEAVY METALS\*

Test Organism	EC <sub>50</sub> **	SD†	CV††	N‡
Algae	0.042	0.005	12	12
<i>Daphnia</i>	0.22	0.04	20	12
Microtox, 30 min	4.98	1.24	25	20
Seed germination	69.93	13.59	20	15
Earthworm‡‡	623.90	124.80	20	9

\* Modified from Miller et al. (1985).

\*\* Effective concentration at which 50 percent of organisms are affected.

† Standard deviation.

†† Coefficient of variation.

‡ Number of tests.

‡‡ Reported as LC<sub>50</sub> = lethal concentration .

However, data of this type are too limited at this time to be able to generalize these conclusions.

Water-soluble solutions of the insecticides aldrin (0.025 mg/l), dieldrin (0.096 mg/l), and endrin (0.069 mg/l) were tested with the bioassessment protocol. Insecticide aggregates of all tests are summarized in Table 3. Algae and *Daphnia* were quite sensitive to these substances, while Microtox and the seed germination tests showed no effect. Earthworms were moderately affected.

TABLE 2. EC<sub>50</sub> TOXICITY VALUES FOR HERBICIDES\*

Test Organism	EC <sub>50</sub> **	SD†	CV††	N‡
Seed germination	<0.17	0.017	10	20
Algae	54.35	19.02	35	8
Microtox, 30 min	68.20	9.82	14	8
<i>Daphnia</i>	>126.55	41.76	33	8
Earthworm‡‡	11,315.00	2,772.00	25	8

\* Modified from Miller et al. (1985).

\*\* Effective concentration at which 50 percent of organisms are affected.

† Standard deviation.

†† Coefficient of variation.

‡ Number of tests.

‡‡ Reported as LC<sub>50</sub> = lethal concentration .

TABLE 3. EC<sub>50</sub> TOXICITY VALUES FOR INSECTICIDES\*

Test Organism	EC <sub>50</sub> **	SD†	CV††	N‡
Algae	0.127	0.019	15	20
<i>Daphnia</i>	0.138	0.026	20	20
Earthworm‡‡	88.33	23.84	27	15
Microtox, 30 min	NE§			
Seed germination	NE			

\* Modified from Miller et al. (1985).

\*\* Effective concentration at which 50 percent of organisms are affected.

† Standard deviation.

†† Coefficient of variation.

‡ Number of tests.

‡‡ Reported as LC<sub>50</sub> = lethal concentration.

§ No effect.

#### Chemical Mixtures

In comparing the relative toxicity of 2,4-D acid (94 percent pure) with the commercial Esteron 99 made up to the same 2,4-D concentrations, an interesting phenomenon was noted (Table 4). The response of algae, Microtox, *Daphnia*, and earthworms to the Esteron 99 (with undisclosed "inert" ingredients) was much greater than it was for the 94-percent pure 2,4-D. This response suggests that the inert ingredients in Esteron 99 might be toxic themselves or that they act synergistically to enhance the actual toxicity of 2,4-D.

TABLE 4. EC<sub>50</sub> TOXICITY VALUES FOR 2,4-D AND ESTERON 99\*

Test Organism	2,4-D mg/l	Esteron 99 mg/l
Seed germination	<0.1	<0.1
Algae	95.8	12.9
Microtox, 30 min	128.0	8.4
<i>Daphnia</i>	>240.0	13.1
Earthworm**	9,830.0	12,800.0

\* Modified from Miller et al. (1985).

\*\* Reported as LC<sub>50</sub> = lethal concentration.

## Hazardous Waste Site Samples

Greene and Peterson (1989) reported on the results of bioassay comparative toxicology assessments at 37 different sites spanning 23 states. They conducted algae, *Daphnia*, and Microtox bioassays on 326 identically prepared samples. More than half of the samples (185, or 57 percent) produced EC<sub>50</sub>/LC<sub>50</sub> responses. Algae produced an EC<sub>50</sub> for 158 (85 percent) of the toxic samples. *Daphnia* produced an LC<sub>50</sub> for 139 (75 percent) of the toxic samples. Collectively, algae and *Daphnia* produced EC<sub>50</sub>/LC<sub>50</sub> for 177 (96 percent) of the toxic samples. Each of the above experiences has contributed to a sense of confidence that the bioassay screening approach to hazardous waste site assessment has merit.

## Application to Remediation

Three chemical and one vitrification soil stabilization treatability procedures were demonstrated at the Western Processing Site. Soils at the site were contaminated with high concentrations of polynuclear aromatic hydrocarbons (PAH). The concentrations ranged from 8.0 to 740.0 mg/kg. Lead was present at concentrations of 1,200 mg/kg, and zinc concentrations were in the range of 5,000 mg/kg. A variety of engineering criteria were employed to assess the success or failure of the stabilization procedures. Among them were the Extraction Procedure (EP) Toxicity Test (Federal Register 1980), the Toxicity Characteristic Leaching Test (TCLP) (Federal Register 1986), and the Solid Waste Leaching Procedure (SWLP) (Green, unpublished data (USEPA), 1984). The EP Toxicity Test was designed to extract and chemically screen for heavy metals and selected pesticides. The TCLP was designed to extract and chemically screen for heavy metals and organic contaminants. The SWLP was designed to provide engineering estimates of the total amount of "leachates" that might be expected from a site. The EP Toxicity and TCLP both employ chemical extractants, thus making them unsuitable for bioassay. The SWLP employs a series of sequential leaches with distilled/deionized water to simulate hydrologic processes.

Unlike the initial chemical screening tests at this site, no PAH's were detected when the soil stabilization demonstration was conducted. Therefore, most analyses focused on heavy metals. Results of the EP Toxicity and the TCLP are summarized in Table 5. According to engineering criteria, the chemical stabilization procedures all worked well. That is, they were all successful in reducing elutriate strengths to levels that allowed water quality criteria to be met directly. The vitrification procedure proved less successful.

When bioassays were applied to elutriates from each of the procedures, various toxicities were shown (Tables 6 and 7). Vitrification (Battelle) produced no toxicity, but was ineffective in terms of reducing leached materials to levels acceptable by water quality criteria standards. Therefore, its lack of toxicity had little bearing on any decision concerning its use as a stabilizer. However, since the other three procedures all worked equally well, but demonstrated various toxicity levels, the logical choice might be to select the least toxic one (Chiyoda). It is interesting to note that stabilization chemicals appear to have increased toxicity to the terrestrial test organisms. However, this "onsite" increase might be acceptable if stabilization is successful in reducing contaminant migration offsite. It

TABLE 5. LEACHING PROCEDURE COMPARISON\*,\*\*

<u>Contaminant</u>	<u>Total</u>	<u>EP Toxicity</u>	<u>TCLP</u>
Zinc	5,000.0	68.000	68.000
Cadmium	27.0	0.360	0.020
Lead	1,200.0	0.530	5.100
Chromium	170.0	--	0.045
Copper	110.0	0.047	0.170
Nickel	3.0	0.067	0.073
Barium	70.0	0.450	0.980

\* Modified from Barich et al. (1987).

\*\* Values expressed as mg/l or mg/kg.

TABLE 6. AQUATIC BIOASSAY TOXICITY FOR TREATED SOIL  
(Degree of Toxicity)\*

<u>Medium</u>	<u>Algae</u>	<u>Daphnia</u>	<u>Microtox</u>
Raw soil	Extremely high	Moderate	None
Chiyoda	High	None	Moderate
Calweld	High	Low	Moderate
Soiltech	Extremely high	High	Moderate
Battelle (vit.)	None	None	None

\* Modified from Barich et al. (1987).

must be considered in view of the total remediation picture. This demonstrates only one application of bioassays in the remediation process at hazardous waste sites. Several other applications can be made (Athey et al. 1987).

The above series of evaluations and applications has led to a revised Biological Assessment Protocol (Greene and Peterson 1990).

#### CONCLUSIONS

Application of bioassessment provides:

- Integration of all environmental and chemical variables.
- An indication of environmentally relevant toxicity potential.

TABLE 7. TERRESTRIAL BIOASSAY TESTS OF TREATED SOILS  
(Degree of Toxicity)\*

<u>Medium</u>	<u>Root Elongation</u>	<u>Seed Germination</u>	<u>Earthworm</u>
Raw soil	None	None	None
Chiyoda	Low	Moderate	Moderate
Calweld	Low	Moderate	High
Soiltech	Low	Extremely high	Extremely high
Battelle (vit.)	Low	None	None

\* Modified from Barich et al. (1987).

- A means of screening a wide variety of samples for acute toxicity.
- An indication of media and organisms at greatest risk.
- A means of ranking problems based on ecotoxicology.
- A means of directing chemical analyses.
- Assistance in making engineering decisions regarding cleanup and remediation.

#### ACKNOWLEDGMENTS

J. C. Greene, EPA Corvallis Environmental Research Laboratory, has been instrumental in conducting evaluations of the biological assessment protocols and in interpreting their responses to a broad spectrum of chemicals. J. Barich, EPA Region 10, Seattle, has played a key role in designing and incorporating bioassays into the evaluation of remediation options. I thank them for their assistance and support in preparing and reviewing this paper.

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FOLLOW-UP INVESTIGATION OF MARINE LIFE AROUND ARTIFICIAL SANDY BEACH OF  
YOKOHAMA MARINE PARK AND PROBLEMS CONCERNING MAINTENANCE

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ABSTRACT

Most of the natural shoreline in Yokohama City has been lost due to coastal land reclamation executed since the opening of the port.

INTRODUCTION

Yokohama City executed the land reclamation work off its Kanazawa section during the period 1971 to 1988 to accommodate factories and other establishments which had to evacuate from the city center in compliance with the City Center Redevelopment Plan.

In this connection, construction of a marine park and development of the artificial island called "Hakkei-jima" have been promoted to restore the shoreline which has been lost because of the land reclamation and to provide recreational facilities for citizens.

This paper reports the results of the follow-up investigations conducted through the past 10 years about marine life which has settled at the "artificial sandy beach," a main feature among the facilities in the marine park, and also describes problems concerning the maintenance and management of the beach.

ARTIFICIAL SANDY BEACH PROJECT

The basic concept for the construction of a marine park initiated in February 1971 was to "create a broad sandy beach where fish and shellfish live and people can gather shellfishes" (Yokohama City Government 1981).

This area is well known traditionally as "Kanazawa Hakkei," a scenic spot; the beach portion of the marine park project appeared in Hiroshige's Ukiyoe "Otsutomo-ro Kihan" (Photo 1). Until the 1960's, the beach was a famous spot for shellfish-hunting. Therefore, in the planning, a primary target was to create a shoreline matching present-day requirements, while considering the historical background, and to make the beach a place where marine creatures live and people can gather shellfishes and participate in marine recreational activities such as promenading and bathing. Then, there emerged a sandy beach approximately 1 km long and 200 m wide at ebb tide or 60 m wide at high tide. Approximately 1.1 million cu m of pit sand with a median grain diameter of  $d_{50} = 0.25$  mm was brought from Mt. Sengen, Chiba Prefecture,



Photo 1. Yokohama--Marine Park sandy beach and  
Hakkei-jima Island

across Tokyo Bay, then temporarily deposited at the sea bottom for 5 years, and finally pumped with a pump dredge to make a beach (Kobayashi, Sugiyama, and Tanaka 1980).

#### INHABITATION EXPERIMENT WITH SHORT-NECKED CLAMS IN NOURISHED BEACH SAND

Since the sand used for beach nourishment is from inland, a test station was constructed with this sand on the existing beach covered by the project from October 1976 to January 1977 to learn if short-necked clams (*Ruditapes philippinarum*) could live in the beach after nourishment (Coastal Development Dept. et al. 1977). A number of short-necked clams from the neighboring beach were collected, marked, and planted around a polyvinyl chloride pipe signpost erected at the center of each of the test zones. Then, how the clams inhabited, grew, and moved was investigated. Also, the secular change in the variety and individuals of benthos, water quality (temperature, specific gravity, pH, DO, COD, SS, CI, and colon bacilli), and bottom material (ignition loss, COD, sulphides, and oxidation-reduction potential) was observed.

As the result, it was found that short-necked clams could live well and grow even in the pit sand, which varied only slightly from the existing tideland. Also, from this it is apparent that the variety of benthic creatures

has become more diverse as time goes by, and the sand used for beach nourishment is no particular hindrance to the environment in which benthic creatures other than short-necked clams could live.

#### PLANNING OF ARTIFICIAL BEACH AND INVESTIGATION OF BENTHOS

In March 1979 the "Construction Technical Manual of Artificial Beach" was compiled by the Ministry of Transport. In this work, "the creatures' inhabitable environment at an artificial sandy beach and prediction of change in the bottom material which makes up its life base" was considered as lacking in knowledge sufficient for the working group to describe. Moreover, around 1971 when this sandy beach plan was introduced, little was known even about the phenomenon of littoral drift which would greatly affect the stabilization of the sand deposited, in spite of the task to reproduce a shellfish-gathering place (Coastal Development Dept. et al. 1979-1988). Therefore, an implementation plan was set up from all pieces of information available at this planning stage, and construction of a sandy beach started. At the same time, it was decided to fill any gaps which would appear later by follow-up investigations and to employ adequate control measures as the construction work progressed.

Accordingly, various investigations were conducted right after the construction of the sandy beach and followed changes in the environment and life at the sandy beach. Items, purposes, and times of investigations are shown in Table 1. Survey points, survey courses of traverse, neighboring topographical features, and sandy beach profiles are shown in Figures 1 and 2, respectively.

The existing seminatural beach of Nojima was added in the fiscal 1983 to the scope of investigation for comparison with the artificial beach.

#### FORM OF SANDY BEACH AS LIFE BASE FOR CREATURES AND ITS CHANGE

After the wave observation by the wave meter at the Kanazawa Bay entrance, the comparison of topographical features before and after reclamation, and the examination of short-necked clams' living environment based upon the research concerning the life history of existing short-necked clams, the following preconditions were set up to determine sectional and plane forms of the beach:

- a. The sea should be calm and the wave height should be no higher than about 80 cm ( $H_o' = 0.8$  m,  $T = 5$  sec).
- b. The depth of water should be no greater than -5 m.
- c. The existing bottom slope should be gentle as about 1/100 on the average.
- d. Living space for creatures should be maintained in the shallow part, mainly during the period between tides.
- e. Sand movement should occur so as to allow habitation of creatures and to prevent aging of the beach.

TABLE 1. ITEMS, PURPOSES, AND TIMES OF INVESTIGATION OF CREATURES AND THEIR ENVIRONMENT AT ARTIFICIAL BEACH IN MARINE PARK

[illegible]

1	100% Special Reagent Sand Dried
2	Water Quality Bottom Material
3	Sand, 30%
4	Water Quality Bottom Material

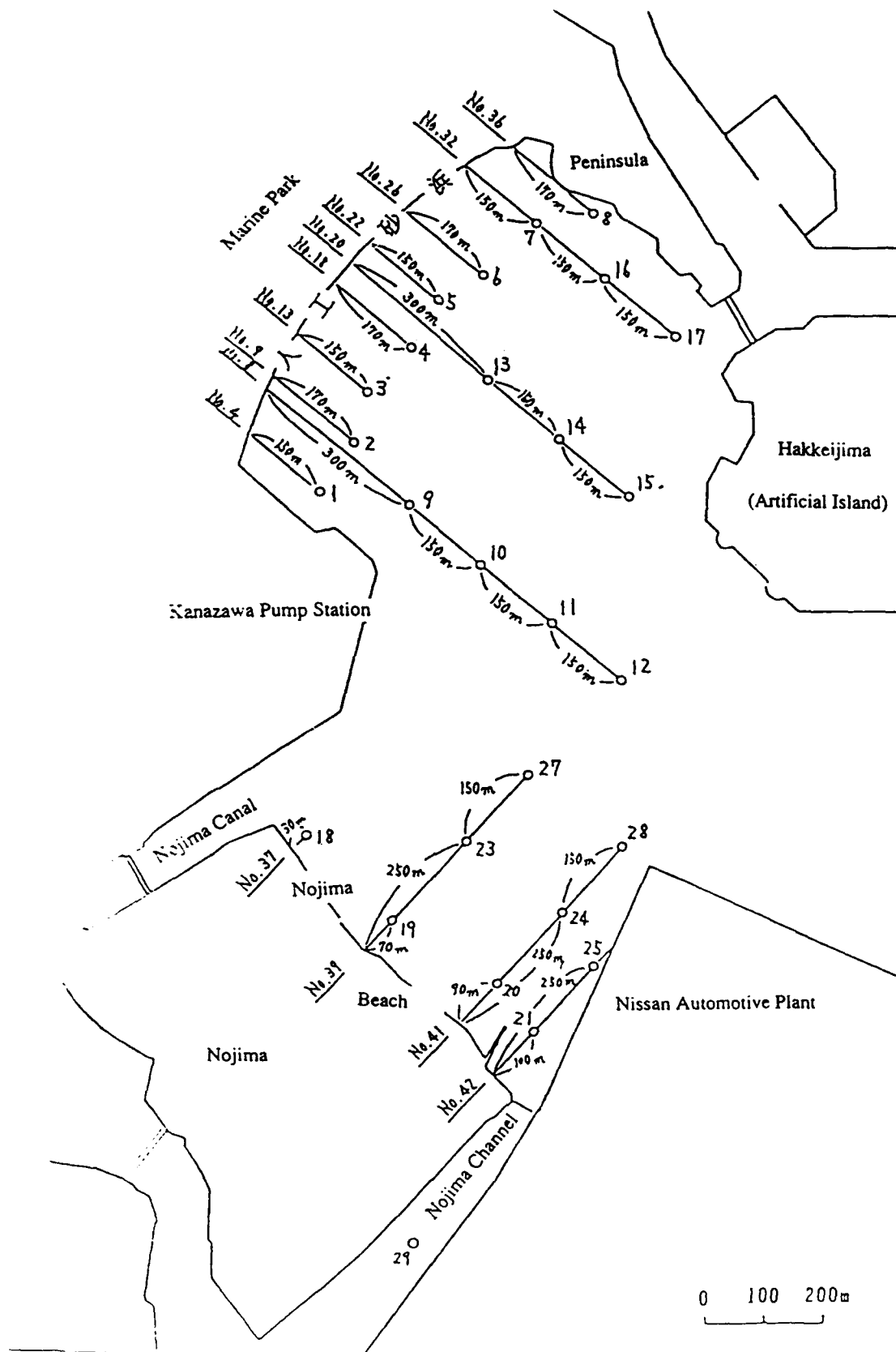
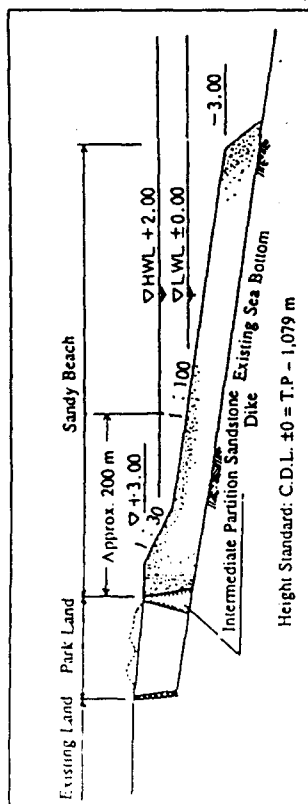


Figure 1. Survey points and courses of traverse



Design Standard Sectional Drawing

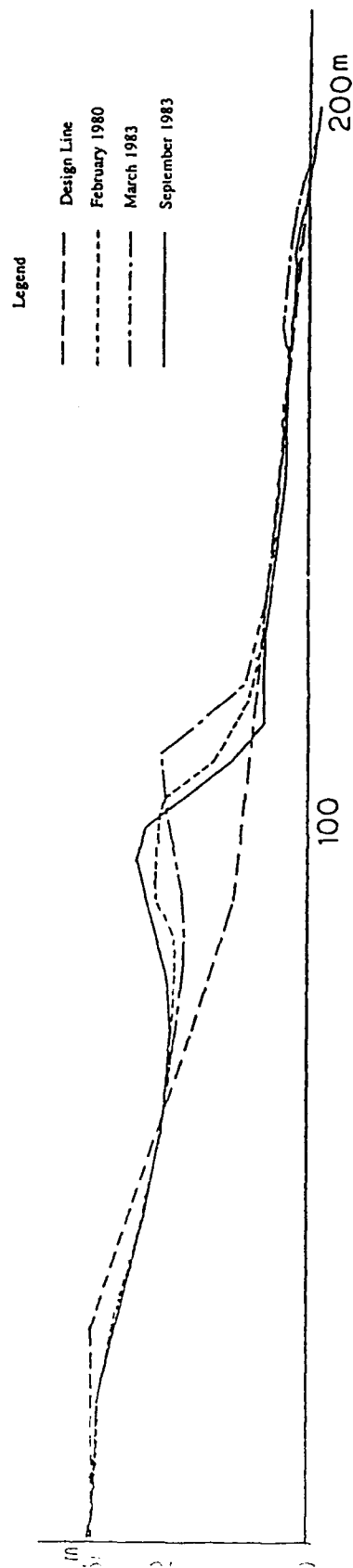


Figure 2. Topographical change of artificial sandy beach (sectional form at the central area)

- f. Aeration and a seawater exchange function to purify seawater should be provided. That is, the breaker zone should be wide and gentle-sloped, and no structure to create a stagnant water area should be built.

Taking all of the preconditions into consideration, the beach profile was designed with foreshore slope of 1:30; inshore slope of 1:100, the same as the existing bottom slope; and beach width of 90 m.

A plane form was determined from the results of an on-the-spot survey of the form of a wave crest line and the pocket beach.

As shown in Figure 2, the sectional form of the beach measured about 4 years after the formation is 1:100 in a depth greater than +1.0 m, which is almost the same as the design slope, and 1:5 to 1:10 from the intermediate tide zone shallower than +0.5 m to the high tide zone crest, though fluctuating seasonally. Thus, the beach is stabilized (Tanaka 1980).

#### WATER QUALITY AT BEACH

##### Water Temperature

Temperature of the water was high in summer and low in winter, regularly changing in a range from 7° to 26° C.

##### Hydrogen Ion Concentration

The maximum concentration was 8.9 in 1980 and 1983, and the minimum over 7.8 very year.

##### Chlorine

The average was about 17 percent with no particular change except during fiscal year 1983, in which it dropped below 10 percent.

##### Dissolved Oxygen

Maximum value was 18.9 mg/l in fiscal year 1985 and 13 mg/l in every other year. Minimum value was 2.5 mg/l in fiscal year 1981 and over 4 mg/l in every other year. Average value was generally 7 to 9 mg/l. No particular change was observed.

##### Chemical Oxygen Demand

Maximum value was 15.9 mg/l in fiscal year 1985, and the minimum value was 1 to 2 mg/l in every fiscal year. Average value was 3 to 5 mg/l. No particular change was observed.

##### Total Nitrogen

Maximum value was over 2 mg/l in fiscal years of 1982, 1983, and 1985, but the average value was 1.4 to 1.4 mg/l. No particular change was observed.

## Total Phosphorus

The maximum value exceeded 2 mg/l in the fiscal years from 1981 to 1985, but the average value showed a declining trend to below 0.1 mg/l from fiscal year 1986.

The water quality at the artificial beach (Figure 3) was better than that at the neighboring Nojima beach or Nojima channel (Coastal Development Dept. et al. 1979-1988). It deteriorates a little in summer and recovers in winter. When viewed over time, it has made almost no change since the beach construction.

## BOTTOM MATERIAL OF SANDY BEACH

Figure 4 shows the secular change of the ignition loss of the bottom material and the grading composition (in September 1988) by the water area from the tideland area at the beach to the offing.

The ignition loss of the bottom material in the tideland area has been more or less 1.0 percent, which is almost no change to date from the time of beach construction. In the shallow water area with a depth of about 1 m, the ignition loss of the bottom material has been 1.0 to 2.0 percent, which shows no substantial difference from that in the tideland. The ignition loss in the water area with a depth about 3 m was somewhat high in fiscal year 1982, but it showed a decrease thereafter and became less than 3 percent in and after fiscal year 1984. Of the existing bottom material with a depth of 5 to 7 m, it was about 6 to 7 percent until fiscal year 1986, but showed a declining tendency thereafter. As to the grading composition, sand (grain diameter 0.074 to 2 mm) was predominant at the survey point where the ignition loss was low, but silty clay (grain diameter less than 0.074 mm) was predominant in the offing where the ignition loss was high. The median grain diameter tended to become larger in the tideland area and smaller in the offing.

Thus, the bottom material of the Kanazawa Bay is corresponding well with the depth of the sea (Coastal Development Dept. et al. 1979-1988). Therefore it is considered that the tideland and shallow-water areas at the beach are not only suitable for shellfish-gathering to be patronized by citizens but are also important as water areas for purifying the seawater by aeration of breaking waves and promoting decomposition of organic matters, and for providing a habitat for marine creatures.

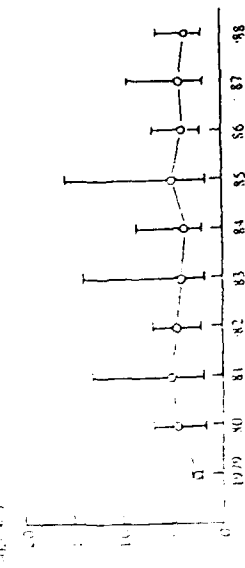
## BENTHIC CREATURES AT BEACH (HABITATION OF MAINLY LARGE BENTHIC CREATURES SUCH AS SHORT-NECKED CLAMS)

### Appearance of Benthic Creatures

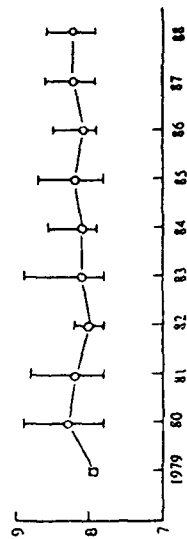
#### Immediately After Artificial Beach Construction

The artificial beach construction work was executed from June 25 to September 2, 1979, by the pump dredge. In December 1979, three months after the completion of the sandy beach, shellfishes *Macra veneriformis* and *Macra chinensis* appeared in large quantity, and in a half year these shellfishes increased as much as 900 g/m<sup>2</sup>, larger toward the peninsula. This phenomenon is considered as influenced by tidal currents (Figures 5 and 6). In September,

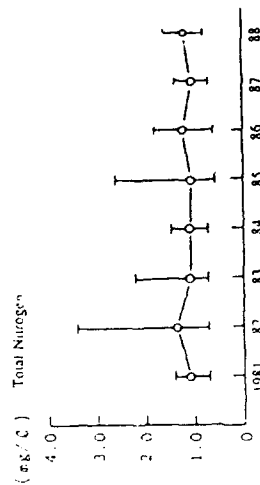
Chemical Oxygen Demand



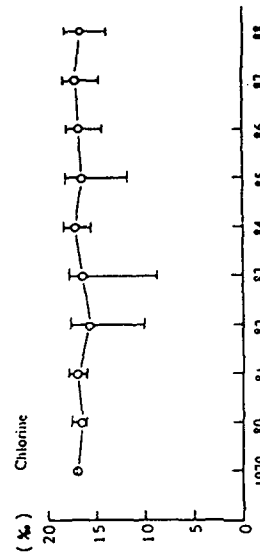
Hydrogen-ion Concentration



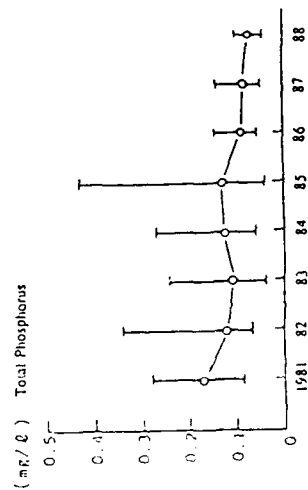
Total Nitrogen



Chlorine



Total Phosphorus



Dissolved Oxygen

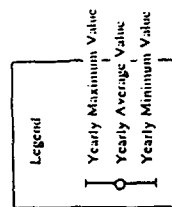
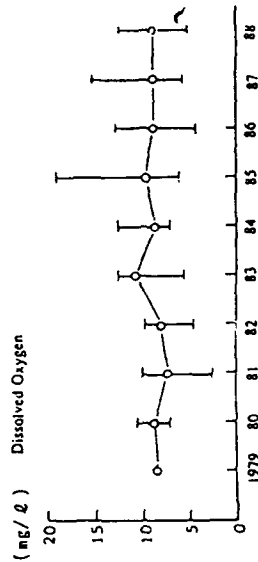


Figure 3. Secular change of water quality at artificial beach (Sta. 5)

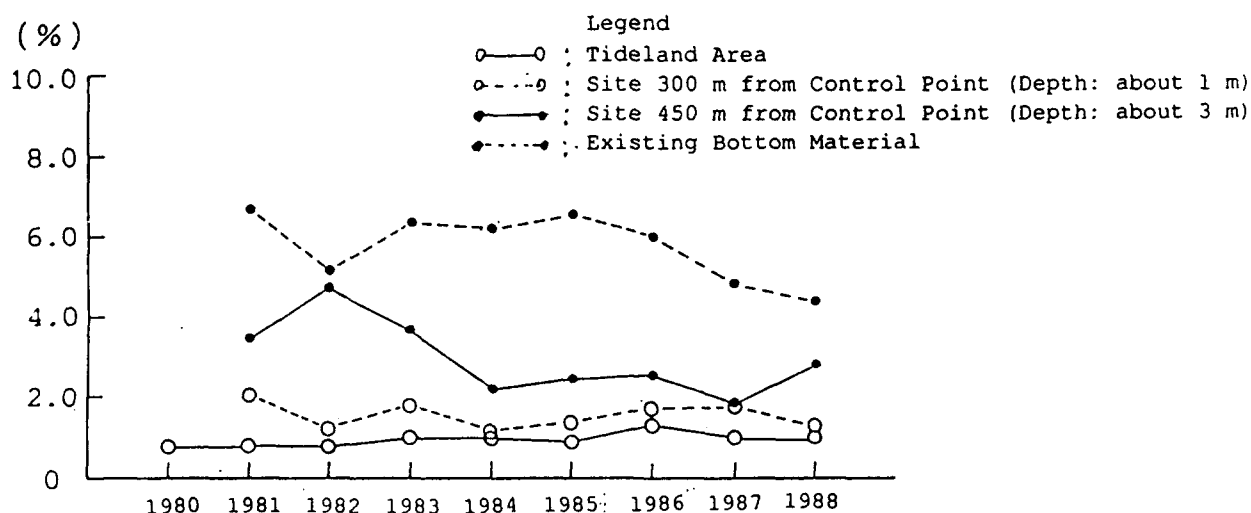


Figure 4. Secular change of ignition loss of bottom material (investigated in September every year)

1 year after the completion of the beach, many spats of short-necked clams had appeared.

#### Secular Change of Benthos

Figure 7 shows the secular change of the average value of the large benthic creatures which were collected in a 1-m-square section at each of the 12 survey points in the tideland area (average ground height +0.4 m) at the artificial beach and screened by a 5-mm sieve.

In about 1 year after the completion of the beach, short-necked clams became the dominant species, and other shellfishes such as *Macra veneriformis* and *Macra chinensis* increased gradually. For the last 3 years, short-necked clams have been maintaining a population density at 800 to 1,000 g/m<sup>2</sup>. *Macra chinensis* inhabited most densely at about 500 g/m<sup>2</sup> in March 1980, shortly after the completion of the beach, but decreased to 100 g/m<sup>2</sup> in fiscal year 1983. *Macra veneriformis* were many initially, and in fiscal years 1982 and 1983. At peak, its population density reached 400 g/m<sup>2</sup> but reduced to less than 100 g/m<sup>2</sup> after fiscal year 1986.

In comparison with the Nojima beach, which is the only natural beach left in Yokohama, the artificial beach showed an increase in the number of short-necked clams.

Thus reproduction of the shellfish gathering-place as one of the objectives of the artificial beach in the marine park is considered successful. A pattern that the shellfish population decreases in the springtime and recovers in the wintertime has set cyclically, as there were so many people (50,000 at most on one day) who visited the beach in the springtime to gather shellfish.

However, the biggest trouble is the reckless hunting of spats less than 20 mm in shell length by shellfish merchants. Thus, such natural resources may be exhausted, and so an appeal is being made to the people by signboard and handbill.

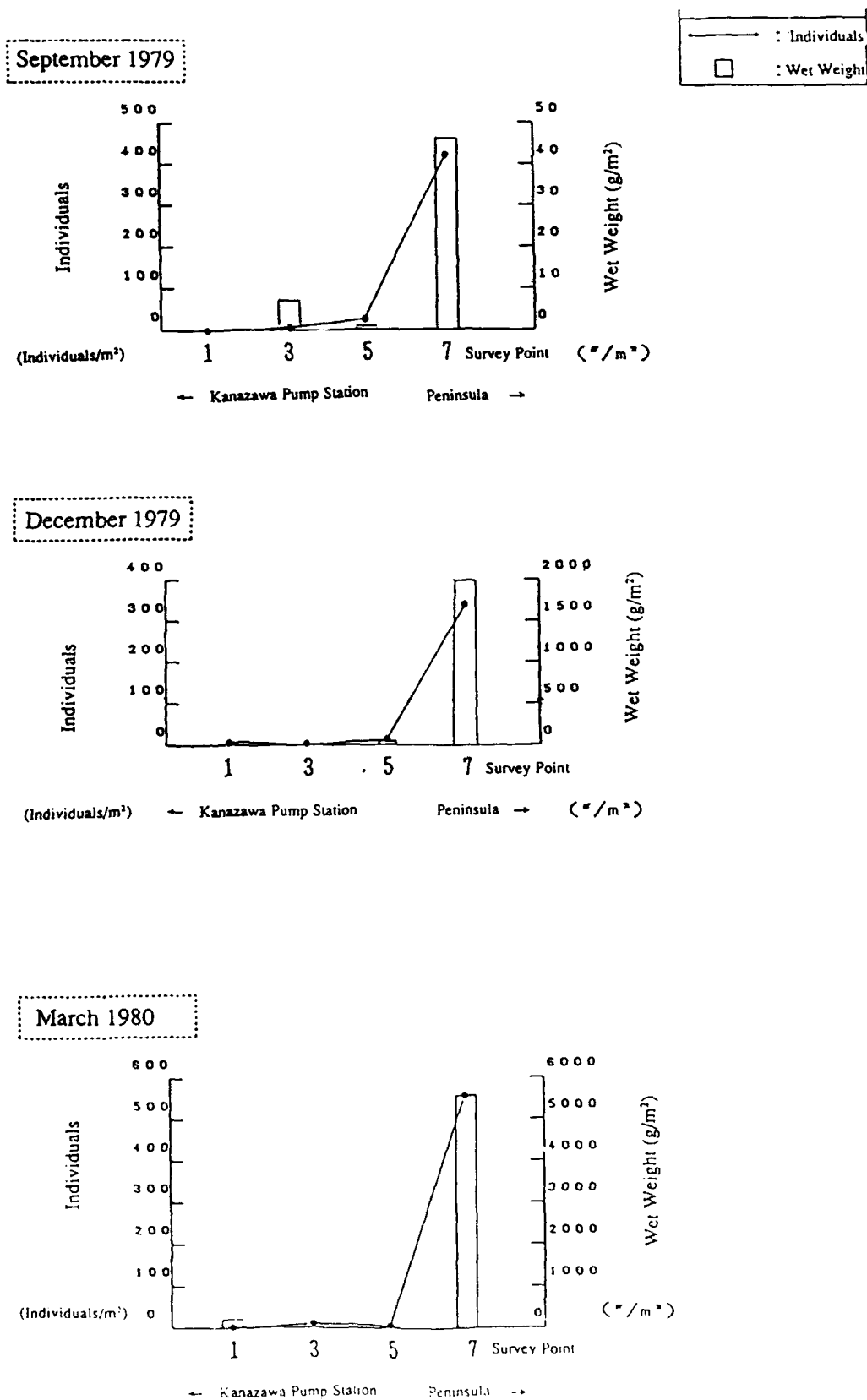


Figure 5. Generating condition of creatures immediately after construction of artificial beach

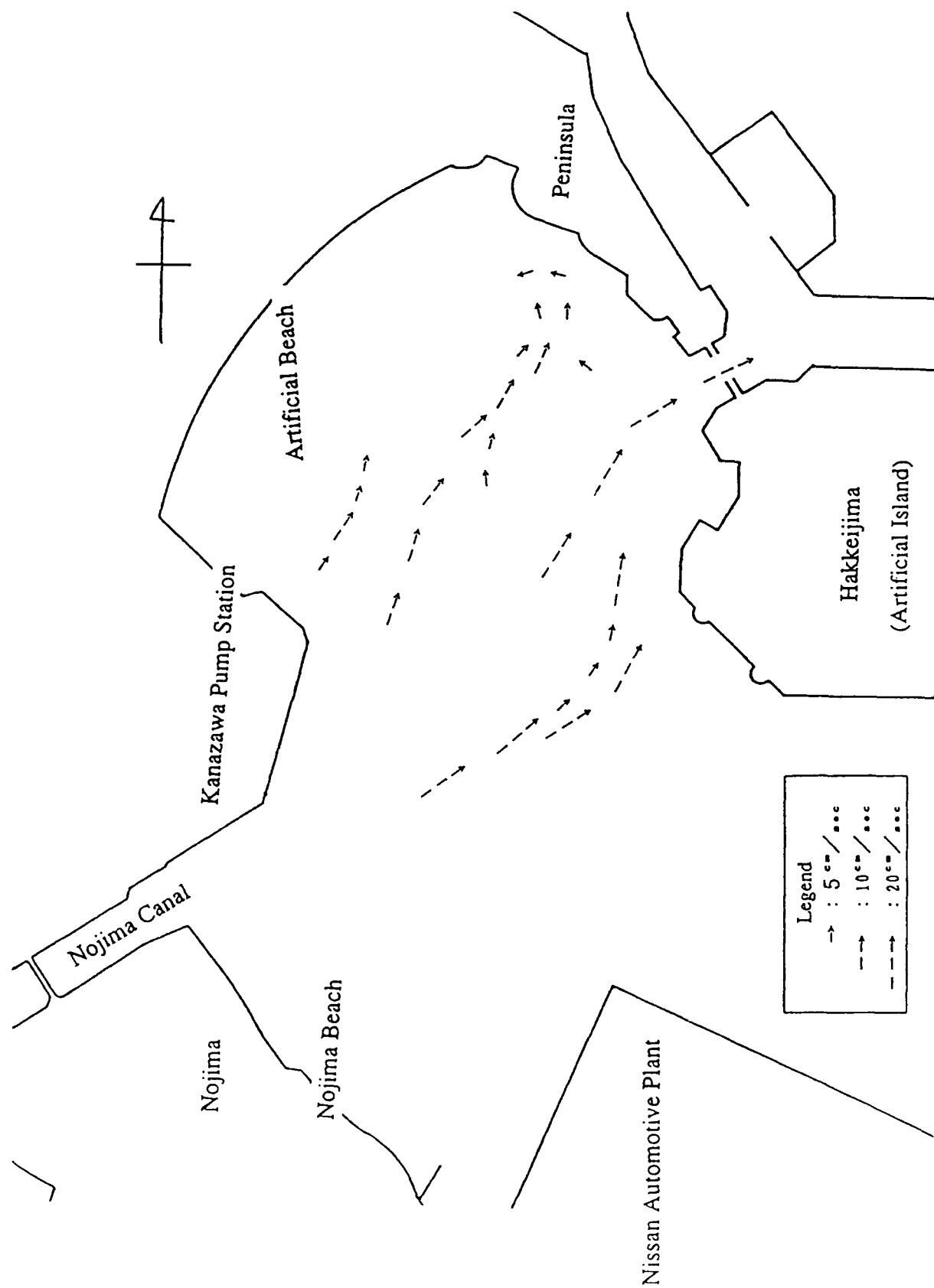


Figure 6. Hydrological regimen on frontage of artificial beach

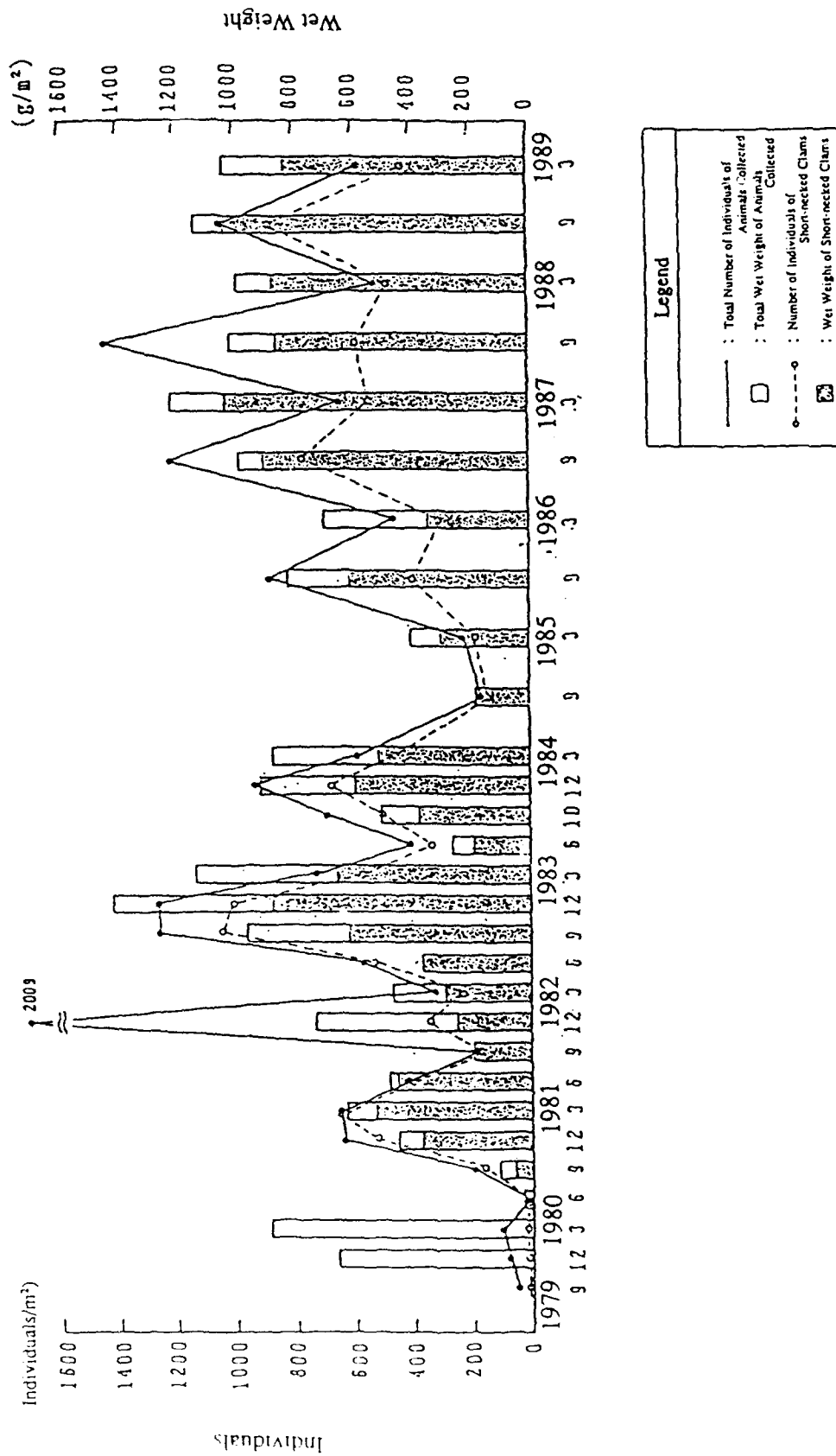


Figure 7. Change of inhabiting quality of large benthic animals

## EMERGENCE OF CREATURES OBSTRUCTIVE TO GROWTH OF SHORT-NECKED CLAMS

What causes the obstruction of the growth of short-necked clams, a main item to be hunted by people at the beach, is described here. According to the research made so far, there are two types of creatures harmful to the existence of short-necked clams, one feeding on them directly and the other checking the growth of them indirectly.

Those creatures who directly feed on short-necked clams are fishes known as black porgies (*Mylio macrocephalus*), surf fishes (*Ditrema temmincki*), eels, gobies (Gobiidae), and flatfishes; sea snails such as *Reishia clavigera*, *Reishia bronni*, *Rapana venosa*, and *Glossaulux didyma*; and octopuses such as *Octopus vulgaris*, *Octopus ocellatus*, and *Octopus minor*. Also, such Crustacea as *Charybdis japonica*, *Leucosia obtusifrons*, *Gaetice depressus*, *Paleomon Ortamanni*, and *Upogebia major* eat spats of short-necked clams.

Among birds, the *Aythya* are known traditionally to feed on spats in the farms of short-necked clams and clams built on the inner parts of the Tokyo Bay. Besides, starfishes are known to do considerable damage on them.

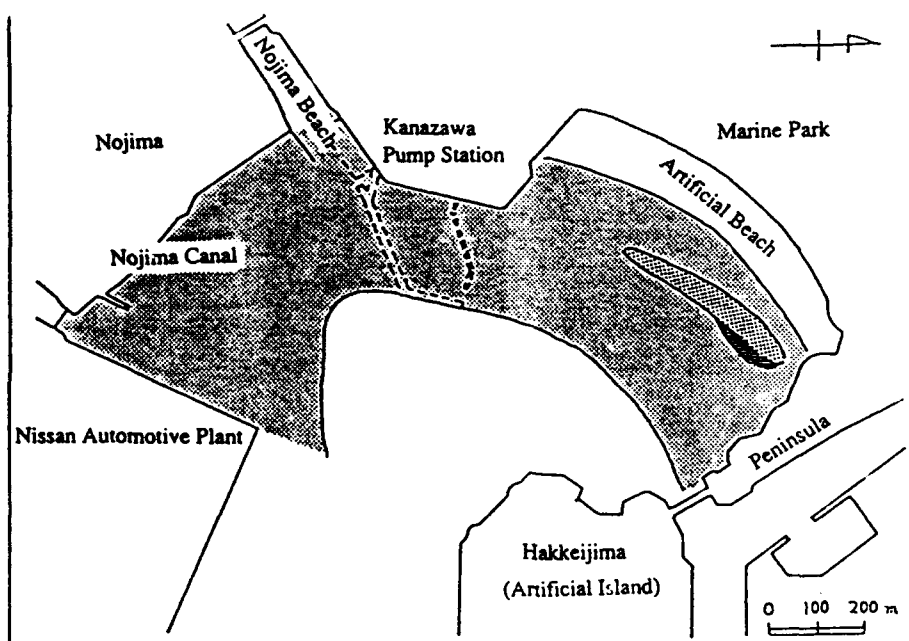
No particular problem has arisen so far around the artificial beach in connection with such enemies. However, *Musculus senhousia*, a bivalve species, and *Ulva lactuca*, a seaweed, which exert the most adverse influence indirectly on them, have appeared. From around September 1980, *Musculus senhousia* were seen to have settled extensively on the sea bottom around the beach and from the following spring. *Ulva lactuca* were seen to have grown in a large quantity. Their areas of distribution were almost the same. As shown in Figure 8, they were more abundant in areas near the peninsula with the artificial beach in the marine park and near the Nissan Automotive Plant on the Nojima coast. It seems that tidal currents are tied up in these areas.

Formerly used as feed for cattle for fertilizer, or as a substitute for the green laver (Moritoshi and Shinzaki 1980), *Ulva lactuca* not only adversely affects the habitation of short-necked clams but also contaminates the beach after being thrown there by waves and decomposing.

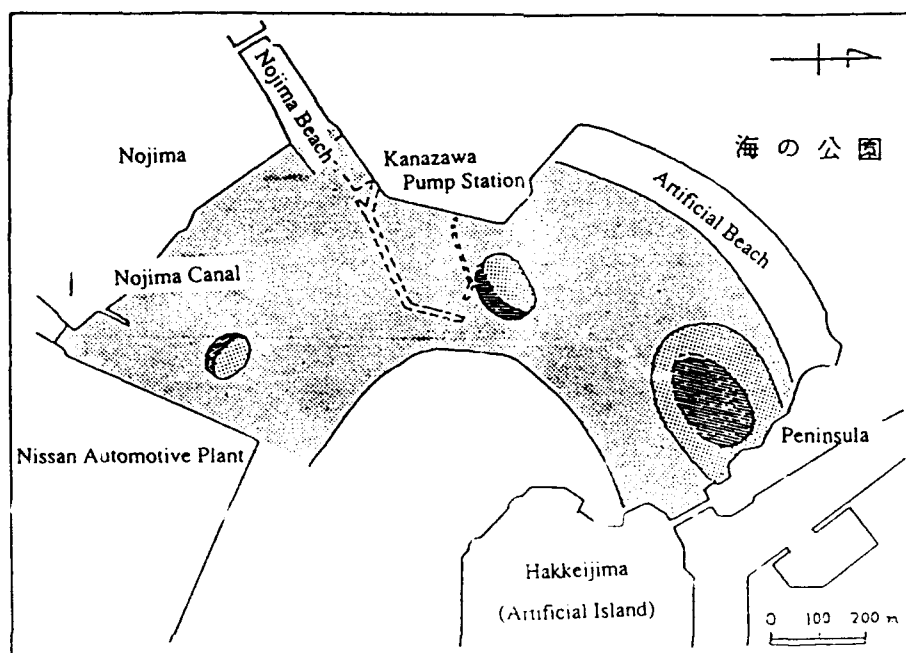
To investigate the status of *Ulva lactuca*, an inquiry was sent to prefectural fisheries experiment stations around the Mikawa Bay and the Inland Sea where *Ulva lactuca* was believed to be increasing. It was essential to know the damage it had inflicted on fisheries and the method of removal, in and after 1982, besides gathering data available at that time.

As a result, the growth environment of *Ulva lactuca* can be generally summarized (World Ocean System, Inc. 1980) as follows:

- a. A water area ranging from the middle part of intertide zone to the upper part of gradually deepening zone (depth: 0.5 to 5.0 mm).
- b. A water area where tidal currents run slowly, i.e., the inner part of bay.
- c. Locating in the vicinity of the river mouth.
- d. Settling at places with bedrock, reef, tetrapod, or revetment.



July 1988



January 1989

- Estimated from Data of Survey  
Courses of Traverse
- : Scatterly, Sparsely Inhabiting Area (Cover Degree Under 50%)
  - : Densely Inhabiting Area (Cover Degree 50-80%)
  - : Heavily Inhabiting Area (Cover Degree Over 80%)

Figure 8. Distribution of *Ulva lactuca*

- e. Floating on tidelands where the bottom is sandy or muddy, or in a shallow water.
- f. Accumulating on a corner of a sea area as blown away by winds.
- g. Daylight and sea water temperature showing little bearing upon the growth of it, apart from its quantity being more or less, as it grows from Hokkaido in the north to Okinawa in the south.

The reason for the abnormal propagation of *Ulva lactuca* is not known yet. As far as the artificial beach here is concerned, the direct cause which seems very probable is that *Macraa veneriformis* has formed a foundation for it to settle down.

From the answers to our inquiry, it is known that nobody is considering at the present time how to remove *Musculus senhousia* or *Ulva lactuca*. Therefore, from July to September 1982, with a small pump dredge of 270P Class S, *Ulva lactuca* and *Musculus senhousia* were pumped up together with sand in a sea area of 1.75 ha with a depth of 0 to 3 m around the artificial beach and then sent through a mud pipe into the reclamation site earmarked for the construction of an offshore artificial island "Hakkeijima." The volume of the sand obtained by dredging was roughly 25,000 cu m. The average thickness dredged was 14.2 cm. Afterward, *Ulva lactuca* was removed by ketaami from the springtime to the early summertime, in which period it was expected to grow up (Table 2).

In July 1988, the artificial sandy beach was opened to the general public as a municipal sea-bathing place. However, in or about 1986, appearance of oysters (*Crassostrea gigas*) as a new creature was recognized (Figure 9). Therefore, from April to June 1988, prior to the opening of the beach, oysters amounting to roughly 19 tons were moved by dragnet and by hand-picking because of their danger to bathers.

From the fact that various marine creatures including such useful fishes and shellfishes as short-necked clams and *Macraa chinensis* live in this area, it is assumed that the marine environment around the artificial beach is improving considerably (Port of Yokohama Promotion Association 1988).

#### CONCLUSION

As mentioned above, the authors conducted various investigations for the past 10 years to obtain information to use partly for the maintenance and management of the artificial sandy beach in the Marine Park of Yokohama City. This paper summarizes the result of such investigations as relating to the use of the beach for shellfish-gathering and sea bathing.

Many things are still unknown to us about how creatures generate and about the environment in which they inhabit, and we are reminded anew of how complicated the mechanism of nature is and how difficult it is to foresee such a mechanism. Traditionally, sea bathing and shellfish-gathering should be recreational activities on the natural beach, and the generation of such things as green laver (*Ulva lactuca*) and oysters is considered as a natural phenomenon, not as an occurrence harmful or unpleasant to humans.

TABLE 2. TOPOGRAPHICAL CHANGE, SEA SURFACE UTILIZATION, AND GENERATION OF SEaweEDS AROUND ARTIFICIAL BEACH

Fiscal Year		1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Topographical Change	Construction of Beach	10 _____	9 _____										
	Construction of 'Hakkejima' Island			10 _____		3 (Altitude + 2m)							
	Construction of 'Kanazawa' Fishing Port									5 _____			
Utilization of Sea Surface	Shellfish-gathering			7 _____									
	Sea bathing											7 _____	
Generation of Seaweeds and Removal of Same	Ulva lactuca and Musculus senhousia (Aunty of Removal in ton)			(58) _____	(85) _____	(40) _____	(500) _____	(866) _____	(565) _____	(365) _____	(199) _____	(608) _____	(307) _____
	Oysters (Crassostrea gigas) (Quantity of Removal in ton)												
												(19) _____	(--)

Note: Except those which are thrown up on the beach, removal of green laver (*ulva lactuca*) and other kinds of seaweed in the sea is made by pump dredger and dredge net, from April to September for 1989.

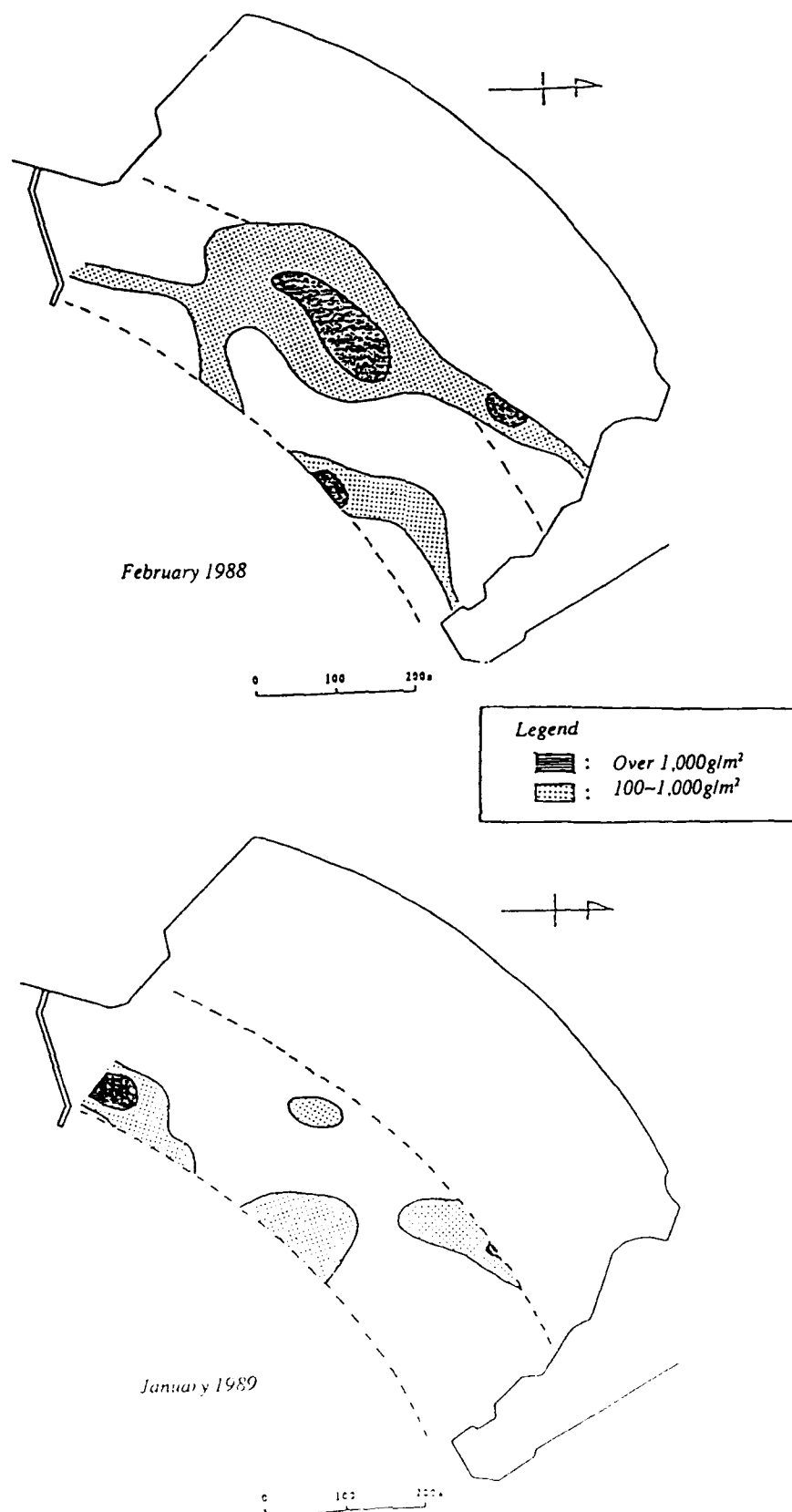


Figure 9. Distribution of oysters (*Crassostrea gigas*)

However, for the beach to be useful as a comfortable place for people, removing these things by artificial means is inevitable, though it is against the law of nature. Thus, the development of an effective removal method is expected in the future for the maintenance and management of this artificial sandy beach.

Together with these measures, artificial problems--for example, generation of waste, disposal of refuse, and protection of spats against reckless hunting--can be solved by improved manners of the people using the beach for the maintenance of a good environment there.

For the utilization of the sea area around the beach, a steady investigation of this is to be carried out continuously, with an interdisciplinary effort (engineering and biology), while the people engaged in the project must regard nature with humbleness and reverence.

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